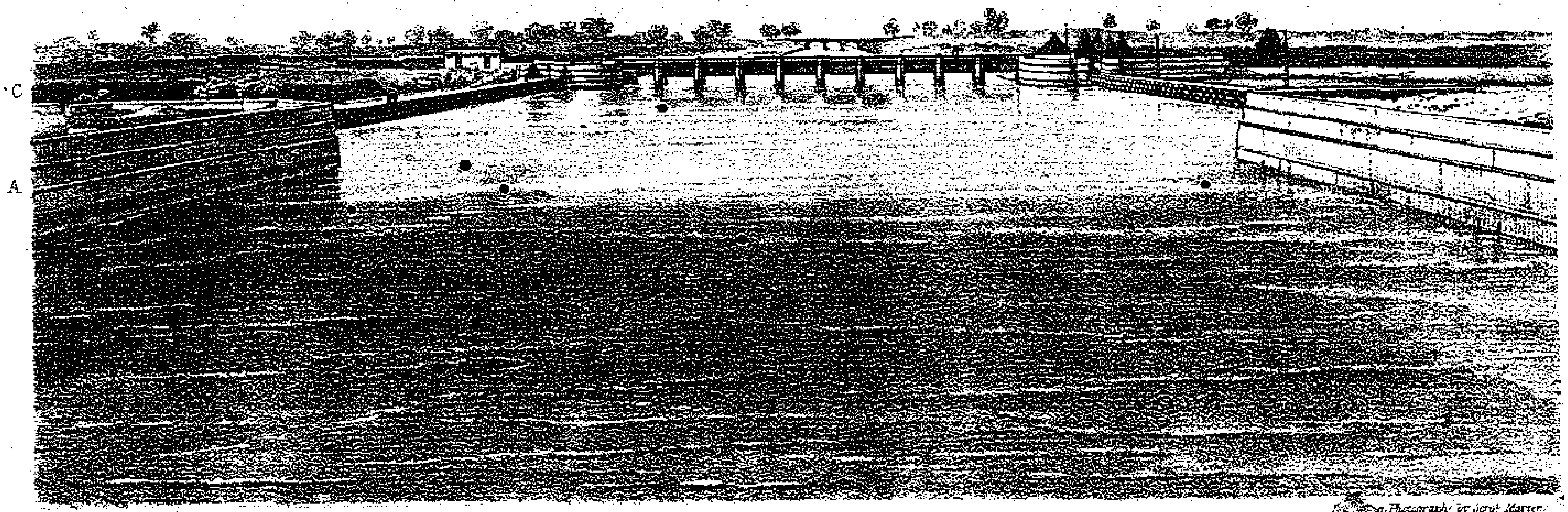

GANGES CANAL, LOOKING DOWNSTREAM; TAKEN FROM THE DHUNOWRI BR[illegible]

Revetment connected with the Dhun[illegible] C. D. Rutn[illegible] torrent crossing the Canal at right angles & running in the dir[illegible]rows.

REPORT

ON THE

GANGES CANAL WORKS:

FROM THEIR COMMENCEMENT

UNTIL THE OPENING OF THE CANAL IN 1854.

BY

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PART III.

DESCRIPTION OF THE WORKS AND DETAILS OF CONSTRUCTION.

THE GANGES CANAL.

CHAPTER I.

DRAINAGE WORKS.

UNDER this head may be placed—

I. *The dams and works connected with them at Myapoor and Dhunowri.*

II. *The works in the Ganges Khadir, for the admission of country drainage.*

III. *The works for the escape of country drainage.*

IV. *The superpassages for carrying the Ranipoor and Puttri torrents over the canal.*

V. *The inlets which form a component part of the bridge and rajbuha channels.*

The works in the first four items are confined to the tract of country lying above Roorkee, and are, legitimately speaking, the only ones which have been expressly designed for counteracting the effects of the mountain torrents, and drainage subordinate to them; those in the fifth item, although to the extent of their capacity capable of receiving water that falls in their neighbourhood, are designed specifically to remedy the interruption to the natural drainage caused by the interven-

tion of the ramps of bridges; the benefits to be derived from them, therefore, are merely local, and restricted to the relief of the land lying on the up-stream side of bridge ramps, and in the vicinity of the choki buildings.

I. *The dams and works connected with them at Myapoor and Dhunowri.*

The works at Myapoor and Dhunowri, although they may be classed under the head of inlets as well as escapes for regulating the supply, fall more appropriately under the denomination of dams and drainage works. I have therefore included them in this chapter; whilst the escapes, which are situated at detached points of the canal channel, are described in Chapter II., under the head of works for regulating the canal supply.

At Myapoor the water reaches the dam through an open channel, without any masonry work for its especial admission; and by closing the regulating bridge waterways, the whole of the supply which arrives at that point, either directly from the Ganges or from the side tributaries, is passed over the dam without affecting in any way the excavated channel. Although, therefore, the term inlet may be properly applied to the water on its approach to the works through the open channel of the Hurdwar branch of the Ganges, it only affects the canal works immediately connected with the dam. In the same category may be included the inlet for the Bochna Nulla, which enters the branch on the up-stream side of the regulator; this, however, is a masonry opening, with a waterway of 20 feet in width, and a fall in the shape of an ogee, forming a part of the buildings attached to the Myapoor works.

At Dhunowri, the inlet for the Rutmoo River is a component part of the works at that place; it delivers the flood-water into the canal channel, to be passed off

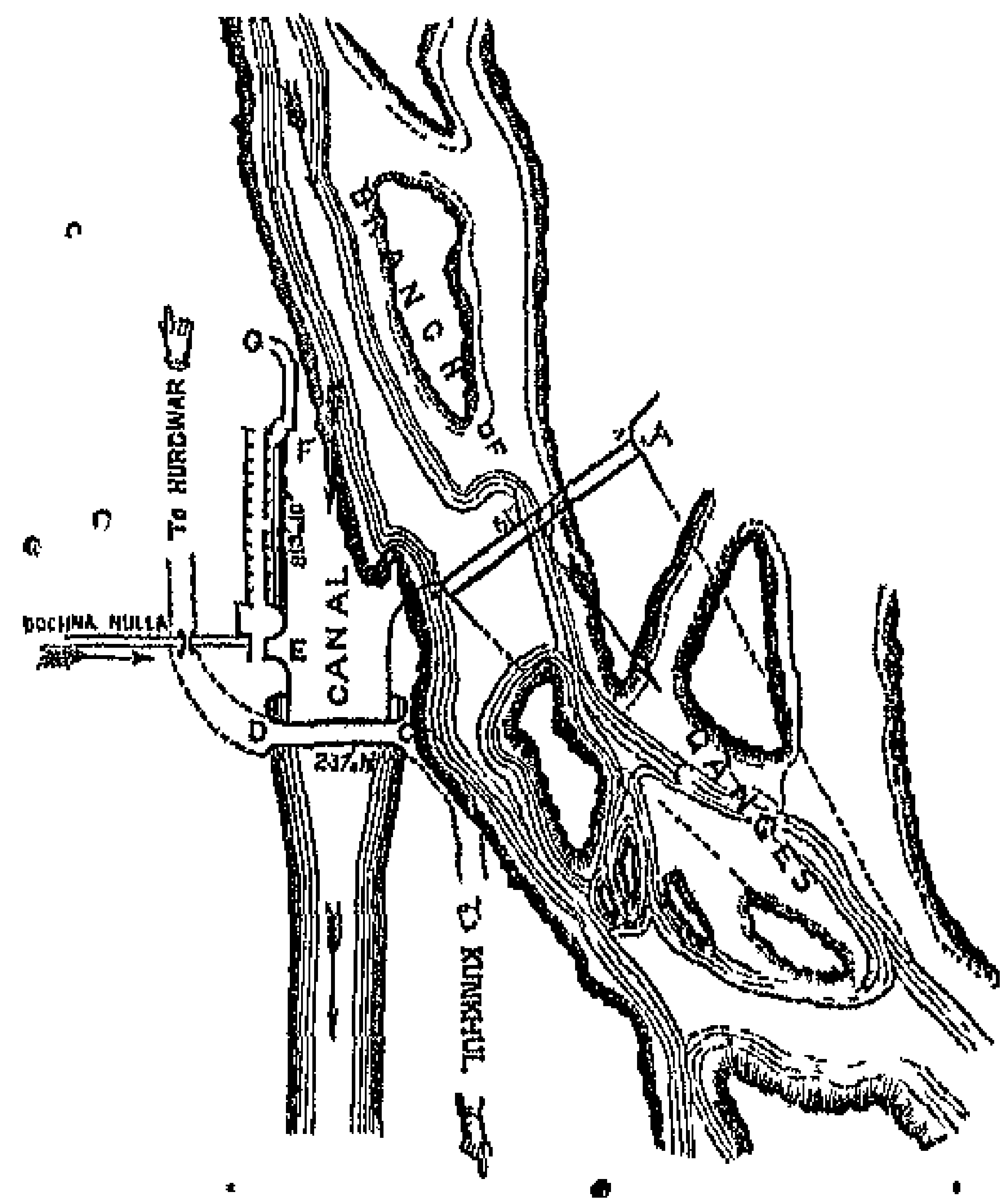
by the dam sluices, which are placed directly opposite to it. The object of the building which forms the inlet, is to give the power of retaining the canal supply within a limited space, which is effected by closing the inlet sluices during the periods when floods are not running. Had this object been unnecessary, and had the inundation which would otherwise have been consequent on the introduction of water into the canal, been of no importance, the design of the works here would have been similar to that of those at Myapoor, in so far that the Rutmoo channel on its up-stream side would have been left open and unimpeded by masonry works of any description. The detail of this inlet, therefore, will more properly belong to the description of the works at Dhunowri, or those on the Rutmoo River. The inlets, in fact, which are attached to the dams at Myapoor and Dhunowri, are altogether peculiar to their positions and uses, and on this account I have included them in the present section.

From the above it will be understood, that the works which come under the head of the First Section are only two in number. They are situated in the Khadir of the Ganges; one being built over a branch of that river between Hurdwar and Kunkhul; the other across the bed of the Rutmoo torrent. The purposes for which they are designed are—to retain the canal supply in its proper channel; and, in their capacity of dams, to prevent it from passing beyond a fixed limit. In that of outlet or escape, they pass off floods during the rainy period, and superfluous water at other times; at the points, moreover, where they are built, they act as regulators to the canal supply. They may be described as masonry platforms thrown across the bed of the river, with their flanks well protected, and with the space between the flanks fitted with sluices. Taking the works of this description which have been built on the Ganges Canal

in their order of precedence, the first that comes under review is the Myapoor dam and dependent works.

The plan of the works, which are connected with the departure of the canal supply from the Ganges River and its branch at Myapoor, is shown in all its detail in Plate No. XIV. of the Atlas.

Diagram 72.



The works consist of a dam thrown across the branch at a point 3,850 feet below the town of Hurdwar, and at the site of what was formerly called the Gunes Ghat. This dam is connected on its right flank by a curved revetment wall with a bridge of ten waterways, built across the mouth of the canal; on the right and up-stream side, a line of ghats and revetments acts as a retainer to the bank of the river abutting upon the right wing of the bridge. The skeleton of the works may be understood by the preceding diagram.

The angle of departure, or that formed by the dam

and the canal alignement, is equal to 126 degrees; the general dimensions of the ground plan are shown by figures on the diagram.

The foundations of a great part of the dam, bridge, and connecting revetments, were laid in as far back as the year 1845, under the executive management of Lieutenant Richard Strachey of the Engineers, under whom the whole of the foundations, and a part of the superstructure, were completed. Lieutenant Strachey left the works in 1846, and was succeeded by Lieutenant Yule; who made over charge to his successor, Lieutenant Alfred G. Goodwyn, in 1848. Under the latter officer the works have been brought to completion. The ground-plan as originally designed has not been deviated from. The superstructure of the bridge, as well as that of the ghats and revetments—in fact, the whole of the work with the exception of the dam sluices and their piers—was completed by Lieutenant Yule, to whom the design of the bridge elevation, steps of access to the ghats, and general outline of the cornices and string courses is due. The Bochna Nulla, a mountain torrent of moderate dimensions, is admitted into the works through an archway of 20 feet in width, which is pierced through the right revetment at the point E in the diagram: the water at this nulla, on its reaching the works, has a drop of 10½ feet, two of which are expended in a head reservoir, offering a concave surface to the current. 268½ feet above the inlet the Bochna Nulla is crossed by a bridge, which, with the bridge over the canal, act as the connecting links between the towns of Hurdwar and Kunkhul. The works attached to the Bochna Nulla were completed by Lieutenant Strachey, and before the period of Lieutenant Yule's assuming charge of the executive duties. Immediately in the rear of the line of ghat which constitutes a portion of the right revetment, and at a distance sufficient to

leave a wide passage between the revetment parapets and itself, a second revetment, broken at intervals by square and octagonal towers, acts as a retainer to the high land which lies at its back. Access is gained to this high land by a flight of steps at the end of the tower wall nearest to the Bochna Nulla.

The design of these towers is derived from buildings of the same description which existed previously to the commencement of the works. A roadway, partly paved and evidently of great antiquity, ran from Hurdwar to Kunkhul, along the edge of the high bank, and parallel to the branch of the Ganges. Its course was continuous, excepting only at those points where the lateral torrents broke through it. It formed the line of communication between the two towns for the pilgrims frequenting the Hurdwar fair; was richly wooded, and marked here and there by noble specimens of the bur (*Ficus religiosa*), peepul (*Ficus Indica*), and other trees loved by the Hindoo. Under the shade of these trees, and at short distances apart from each other, were bytuks, or places upon which fukeers and other holy men sat and received the adulations of their admirers. These bytuks consisted of octagonal or square towers, not exceeding 7 feet in height, approachable by a flight of steps, and frequently situated in the middle of a chubootra, or platform of masonry. They were, in fact, the earthly palaces of the fukeers; each had its possessor, and every separate bytuk had its peculiar sanctity. To whatever extent their owner's intermediate wanderings may have led him—whether to the snows of Gungootri, or to the burning plains of Juggurnath—each successive year exhibited to the admiring pilgrim the same fukeer sitting in the same bytuk, in all probability with the same uncombed hair, and with the same ashy, unwashed, and unshaven countenance. (See *Vignette*, pp. 104 & 383, vol. i.)

As a necessary consequence of the excavations at the canal head, and their position relative to the bank and road, a number of bytuks equal to that which has been constructed, had to be pulled down. In rebuilding these, advantage was taken of the opportunity to place them as ornamental features in rear of the bathing ghats, and in the position, in fact, in which they are now situated. This position is not far removed from that occupied by them originally; and a large bur-tree, which, in all probability, was the centre of attraction to the neighbourhood, shading with its gigantic arms the old bytuks, necessarily removed, now performs its former office for the new buildings, standing on an esplanade prepared for its reception, and protected on the river side by a retaining wall of masonry, as shown in the diagram at the letter G.

I have elsewhere stated that the channel which has been excavated from the Ganges to the Myapoor dam and regulator, is 300 feet in width, on a slope of 8·59 feet per mile. On this slope also, the tail excavation from the dam towards the main river at Kunkhul has been excavated: the extent to which this has been carried, is shown in a purple shade on Plate No. XIII. of the Atlas. The different improvements that are proposed in the neighbourhood of Hurdwar and the bathing ghats, with different suggestions for facilitating ingress and egress to the water, having all been described in Chapter II. of the Second Part, I shall proceed with the detail of the dam works, the outline of which, together with that of the branch, previous to its having been touched by the excavation, is shown in the foregoing diagram.

The left flank of the dam, it will be observed, abuts upon an island, in which nearly one half of its full width was excavated. The island at the point of contact, although terminating at a short distance below the work, is composed of compact earth and shingle, and affords a sound

and efficient resting-place for the flank walls. The right flank falls within the precincts of the branch, as it existed at the period when the works were lined out, and is consequently backed by shingle and soil excavated from that portion of the mouth which lies north of the regulator. The outline of the earthwork and embankments, as well as that of the dam, bridge, and revetments, as they now exist, is shown in diagram 72 by plain lines.

The floorings of the dam and of the regulating bridge are laid on one level, and the front line of the latter is the zero upon which the whole of the canal excavations are referable. The zero point was fixed by me on my original survey; it was, in fact, the bed of the branch at that period, as nearly as the calculated bed levels of the canal, between the head of the first set of falls at Bahadoorabad, and the foot of the Gunes Ghat, before alluded to, would admit of.

The slope of the branch channel, from the Ganges to the flooring of the Myapoor regulating bridge, is, as I have before said, 8·59 feet per mile; that of the canal channel below the bridge, 2 feet per mile; the change of slope, therefore, is a very remarkable one. The beds of all the rivers consist of large and small bolders, and the supply of water throughout the whole of the year, excepting during floods, is pure as crystal. The effects upon the canal bed on the up-stream side of the dam, as well as along the line of the canal, from its mouth downwards, will doubtless be shown by deposits, which will be increased by the influx of sand and shingle brought down in the Lulta Rao; in a minor degree, deposits also will be due from the Bochna inlet. I believe that such deposits are unavoidable, and that periodical clearances will be required; their effects, however, will not be prejudicial to the maintenance of supply.

The dam itself, which is 517 feet between the flanks, is pierced in its centre by fifteen openings of 10 feet wide each; the sills or floorings of each opening being raised $2\frac{1}{2}$ feet from the zero line. These floorings are so constructed, that if necessary, they may be removed, and a flush waterway be obtained as low as zero. The piers between the above openings are 8 feet in height, so that the elevated flooring leaves the depth of sluice-gate equal to $5\frac{1}{2}$ feet. The piers, however, are fitted with grooves for the admission of sleeper or vane planks, to which I purpose restricting the apparatus for closing the sluices, until experience has been gained of the effects of deposits on the up-stream side of the works, and the advisability, or not, of maintaining the raised sill to the openings. There are great advantages in the sill being raised, with respect to facilitating the opening and shutting of the sluices; the arrangement also reduces the gates to a moderate height, and consequently to a more manageable dimension for working; it admits, moreover, of the sluices being opened and closed in a much shorter period of time. Opposed to these advantages, however, is the certain consequence, I imagine, of deposits arising from a bar of masonry raised $2\frac{1}{2}$ feet above the true level. The adoption of this bar, it will be understood, is purely experimental; and should its existence be found hereafter to be detrimental to the works, it can be removed.

The centrical sluices above described are connected to the flanks by overfalls, rising in gradations of one foot on three series; the overfall nearest to the flank being raised 10 feet above the zero point. The flank walls themselves are $18\frac{3}{4}$ feet in height, exclusive of cornice and parapet, which rise 5 feet above them. The top of the overfalls on the right and left, as well as that of the piers, is flat; the former being an esplanade varying from 7 to 10 feet in width, which during dry weather is connected by a

temporary communication formed by planks thrown across the sluice openings. This esplanade is at each extremity terminated by a flight of steps, which gives access to store-rooms; in which, when the dam is laid open, and the woodwork removed, the latter is lodged for security. The two buildings for this purpose are situated on the flanks; their floors are raised 20½ feet from the zero point, and their interior dimensions are 30 feet in length by 16 feet in breadth.

The flank revetments, which are built on the right and left of the down-stream side of the dam, and between which the escape water has to pass, have been designed with an inclination inwards equal to 13 feet on a length of 80 feet. The principle on which a wall placed in this direction is supposed to act, is fully described in the chapter on Falls; as in the tails of those works it has been carried out very extensively. Its main object is to keep the current in the centre and away from the sides, and it is more economical in its construction.

The transverse width of the dam platform is 44 feet, measuring from the up to the down-stream face of the work. Of this measurement 20′ 11″ are given to the tail which delivers the water upon the natural bed of the river, consisting of large bolders and shingle.

The revetment which connects the right flank of the dam with the regulating bridge, is a plain wall equal in height to the dam flanks, and with a slope or batter of 2½ in 20 feet in height. This revetment, on its approach to within 50 feet of the bridge, terminates in a line of ghat, or flight of steps, which passes from the higher levels to the bed of the canal. The up-stream wing or flank of this flight of steps corresponds in form with that of the wing of the bridge, with which it has a uniform curve.

The regulating bridge has ten bays or openings of 20 feet wide and 16 feet high each; each bay being

fitted with shutters and apparatus for either opening or closing it. The breadth of the platform on which the piers rest is 48 feet, exclusive of the cutwaters, which project 4 feet beyond it. The roadway is 37′ 9″ wide between the rear parapet and the up-stream front windlasses; it acts as the main line of communication between Hurdwar and Kunkhul.

My design for regulating bridges has invariably grooves appended to both the up and down-stream faces of the bridge. The latter are useful when accidents occur to the front gates, or to the apparatus for using them; and they provide an alternative which without them does not exist. In the present case the deviation from the original design for the superstructure, to which I have before alluded, has deprived us of these accessories; and it was not possible, without a total reconstruction of the rear face of the bridge, to restore them. The design of shutters for closing the regulators is different to that which has been practised on the Jumna canals; it affords much greater facilities for working, and secures either the closing or the shutting of the bays in a much shorter period of time. Both of these objects are of great consideration when we are opposed to the immediate action of the Ganges; the extreme high water being, agreeably to a register kept for the last twelve years, equal to 15 feet upon the zero line.

On the Jumna regulators a drop gate is used in a simple groove, and sleepers with a scantling of 6″ square are dropped upon the top of the gate. Both time and labour are required to close or open the bays when fitted with apparatus of this sort, but it has always acted very efficiently; and opposed to the Jumna floods, has done its duty very well. It must be recollected, however, that on the Jumna canals we have neither the same volume of water to contend against, nor the same

number of bays to open and shut, that exist on the works which we are now describing: it was necessary, with ten bays upon which the safety of the works depended, to devise some quicker method than that which acted for three, and, if possible, to economize the labour required for using the apparatus. The following diagrams will show in vertical section the method which is in use on the Jumna, and the improved method which I have adopted in the present case.

Diagram 73.

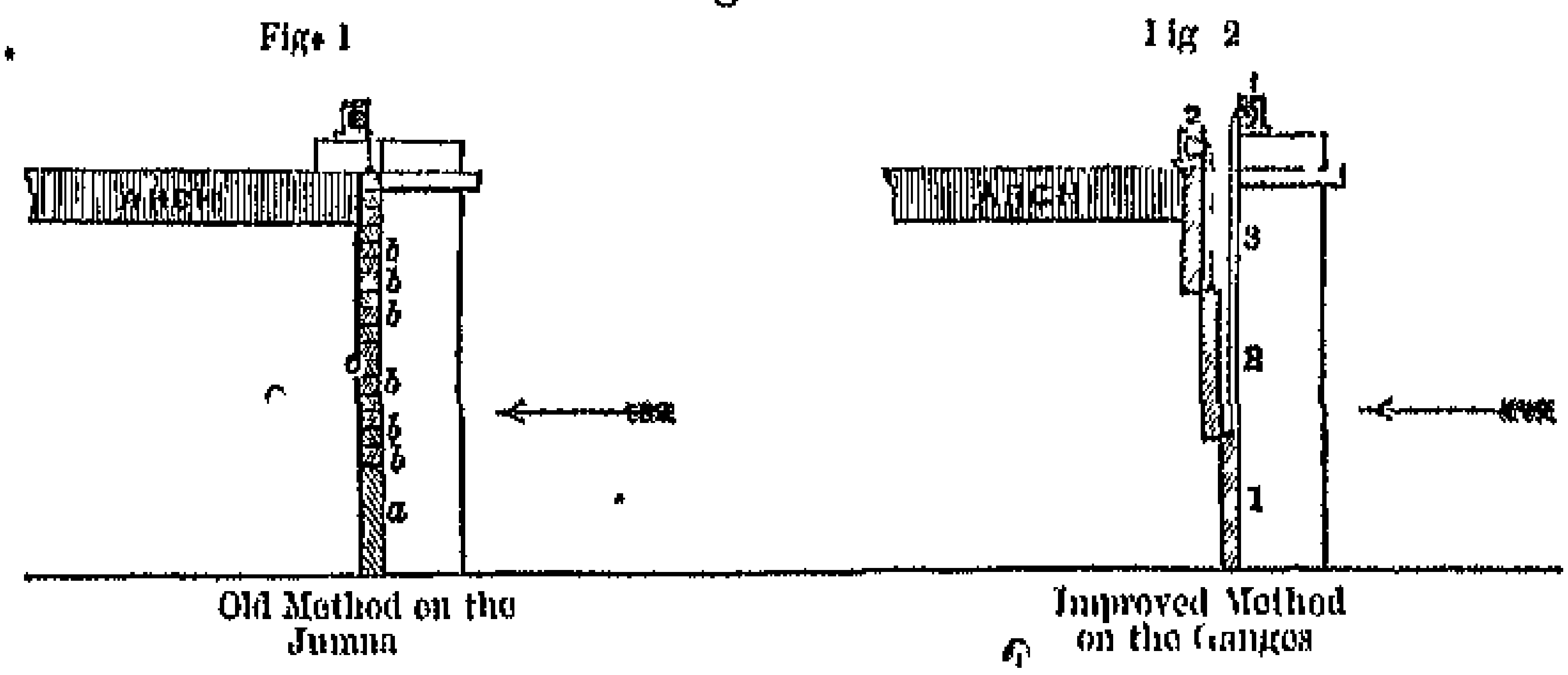


Fig. 1, it will be observed, represents the groove and its cutwater opposed to the up-stream current; '*a*' represents a gate 5 feet in depth, which is kept suspended in dry seasons, and is dropped down on the expectation of floods; *b*, *b*, *b*, show the sleepers or long bars of timber, which, when the chains are removed from the gates, are successively dropped upon them until the bay is closed. The time that this takes is equal to eighteen minutes; the whole operation has been frequently carried on in my presence, and the period taken has been accurately timed. The perfect efficiency of this species of shutter, in the hands of our native establishment, has been tested by me, by actual residence on the spot during the rains, and by personal superintendence of the machinery.

Fig. 2 shows the improved design, gained by the use of two windlasses. The bay or opening, it will be

observed, is divided into three series, the more advanced one having its sill on the zero level; the central and rear ones having their sills elevated in heights of 6 feet, retrograding towards the face of the bridge. The shutter marked No. 1 is dropped from a windlass on the bitt-head 1; that marked No. 2, from the bitt-head 2; that marked No. 3 consists of sleepers, which are raised and lowered without the aid of a windlass. The three gates, therefore, are quite independent of each other; each has its own sill to rest upon; and the whole can, if necessary, be worked simultaneously. The great advantage of this method will be understood, by supposing that a supply of water not exceeding 6 feet in depth is required for canal purposes. In this case, the whole of the shutters 2 and 3 may remain closed; and, when floods come on, the whole of the waterway may be stopped by releasing one set of gates only.

Supposing, again, that the maximum supply of 10 feet in depth is passing down the canal; and that to admit of this, it is necessary to have both the No. 1 and No. 2 shutters raised; No. 3 will still remain closed; and as both No. 1 and No. 2 shutters are suspended on separate windlasses, both can be simultaneously relieved, to the effective and almost instantaneous closing of the whole of the regulator. It will be necessary for navigation purposes (dependent on the headway required for boats), to have one of the bays with its shutters open; but as during flood periods neither boats nor rafts are likely to frequent this part of the river, no inconvenience from this source need be anticipated. The machinery attached to these gates is of the most simple description, intelligible to the commonest labourer on the works, and not liable to disarrangement. It consists of windlasses, which work in sockets embedded in wooden bitt-heads, with ratchet wheels and catches; the windlasses being turned by hand-

spikes. The chains are on the bar principle, in lengths of 3 inches, with plain rivets; and the shutters are mere planks, strung upon iron rods, held at their lower ends by nuts, and terminating above by rings countersunk for fixing the chain upon. The wood used is saul (*Shorea robusta*), the staple timber of the Sewalik forests.

The above will, with the addition of Plate XIV. of the Atlas, give a full exposition of the dam and regulating bridge; it being understood, that when the shutters of the latter are down, and the bays are closed, the water is passed off through and over the dam, the sluices of that work being opened for the purpose: the system, therefore, of admitting and regulating the supply of water into the canal head by the works above explained, will need no further description.

I have before noted, that a ghat, or flight of steps, is the connecting link on the left, between the dam revetment and the regulating bridge. A ghat, identical, both in design and dimensions, is also symmetrically situated on the right. From the up-stream flank of this ghat, a straight line of revetment, on proportions similar to those on the left or opposite side of the canal, meets by a curve on its extremity, the inlet of the Bochna Nulla, the canal face of which is equal to 50 feet in width. A corresponding and semicircular curve gives a limit to the inlet works on their up-stream side, and connects them with a line of ghat of 385 feet in length. The ghat is approached by a flight of steps placed centrically on its length, and abuts at the up-stream end, upon the fukeer's revetment. This revetment, with a species of berm or faussebray on the canal side, was built for the protection of a masonry platform, from the centre of which a bur-tree, before alluded to, rises. This noble tree is well protected on the canal face by the existing works, and the line of bytuks I have described as constituting a part of the revetment in

rear of that of the ghat face, restores to a certain extent a harmony between the works recently built, and those which existed on the ancient line of paved roadway.

The fukeer's revetment, and the building, for whose protection the works in its neighbourhood were designed, are much elevated in position. Although at a distance of only 417 feet from the horizontal esplanade on which the regulating bridge and other works attached to it are laid out, the rise to the fukeer's building is 10 feet. In my original plan for this work, the difference of level was gained by a slope, or inclined plane, ascending from the Bochna inlet to the fukeer's building. Upon this plan the elevation has been completed; the effect, however, is by no means pleasing, the leading cause of which is an absence of parallelism in the composition; the upper line being on a slope, while the lower one is horizontal. It would have been better, in all probability, to have continued the esplanade on one level to the foot of the fukeer's buildings, and at that point to have given steps of ascent to the front and a ramp to the rear. The whole of the work, however, was completed before my return from England in 1848, and it was not thought worth while to make alterations, which would necessarily have been very expensive ones, and after all would only have been an improvement, in so far as appearances were concerned. This part of the work, therefore, has been left in the state in which it was originally built, partly under the design of Lieutenant Strachey, and partly under that of Lieutenant Yule; the whole having been completed by the latter officer.

I may observe, in concluding my remarks upon these buildings, that it would have been both unwise and unnecessary to have raised the roadway of the regulating bridge, and by this method to have placed it in closer correspondence with the level of the fukeer's buildings,

and of the embankments on the down-stream side, which are also much elevated, consequent on the enormous extent of the canal excavations. It is our object to limit the extent of waterways in the regulating bridge to that capable of admitting the required supply, and of giving free and unimpeded passage to boats; beyond this, every additional square inch of waterway is not only unnecessary, but is a positive evil; it would, therefore, be the desire, rather to diminish than to increase the height of the bridge, and to depress rather than to elevate its roadway. The want of elevation, however, has led to the necessity of the awkward ascent to the fukeer's building; and on the down-stream side of the bridge, to as awkward an inclination of the roadway embankment, to meet the bridge roadway levels: in fact, with the exception of the esplanade between the bridge and the dam, and the roads of approach from the country, which are all in one horizontal level, the bridge is reached by downward descents, which, although on small angles, by no means improve the appearance of the works.

Plate No. XIV. of the Atlas enters very much into detail as to the construction, and to material used in the building of the Myapoor works.

In laying in the foundations of the dam and bridge, which were in progress previously to my leaving India in 1845, spring water was met with, leading to great inconvenience. These foundations, which consist of unbroken curtain walls, with cross-bars between them, were sunk to a depth of 6 feet, and built entirely of bolders and cement. A great portion of the massive part of the superstructure of the works was also built of the same material, with brick bond, as represented in Fig. 6. Where bolders were not used, bricks were employed; and of this material the whole of the facings and more delicate parts of the structure were made. The steps of the ghats, and

approach thereunto, are faced with sandstone procured from the hills in the neighbourhood—a material of very uncertain quality, and which, as a rule, I have rejected from the works. This sandstone has been used in the bridge in a variety of ways, most beneficially, in my opinion, in the grooves, the difficulty of altering which to adapt them to the regulating shutters, affords a fair exhibition of the strength of the material when carefully selected. The whole of these works are stuccoed with a cement of the following proportions:—

1 part Lime (Stone).
1 " Soorkee.

The proportions of cement used with the different species of masonry are as follow:—

Bolder Masonry.	Brick Masonry.
1 part Stone Lime.	1 part Stone Lime.
1 " Soorkee.	1 " Soorkee.
1 " Sand.	

The total amount of material expended in these works is shown in the following table, to which is appended the rates at which the different varieties of work were executed.

	Cubic Feet.
Total Cubic Contents of Masonry	520,101

MATERIALS EXPENDED.

Bricks, 12″ × 6″ × 2½″	364,821
Do. 12″ × 6″ × 2″	535,744
Do. Small (native)	2,700
Bolders	335,000 maunds.
Stone Lime	98,690 cubic feet.
Soorkee	96,991 Do.

RATES.

	RS.	A.	P.	
Brick Masonry	19	10	5	per 100 cubic feet.
Bolder Masonry	9	0	5	per Do.
Plastering	6	5	11	per 100 superficial feet.

Small as the arches of this regulating bridge are, they appear to have been constructed with wooden centerings, instead of on the effective and economical method adopted by the natives. The results have been curious: the cost per 100 cubic feet of arched masonry, including the centerings and contingencies thereunto attached, having been rupees 35-1-9. This heavy charge is, of course, owing to the whole of the cost of the carpentry and woodwork of the centerings being chargeable to this work alone: there were no other arches of the same dimension in the works, excepting in the regulating bridges, of which that attached to the Rutmoo was the only one in the neighbourhood; and to this the woodwork referred to could only have been transported at a serious expense. It will be seen in the summary of rates on the latter, that the use of earthen centerings produced a rate for the archwork per 100 cubic feet of rupees 19-6-0 only.

THE DHUNOWRI WORKS.

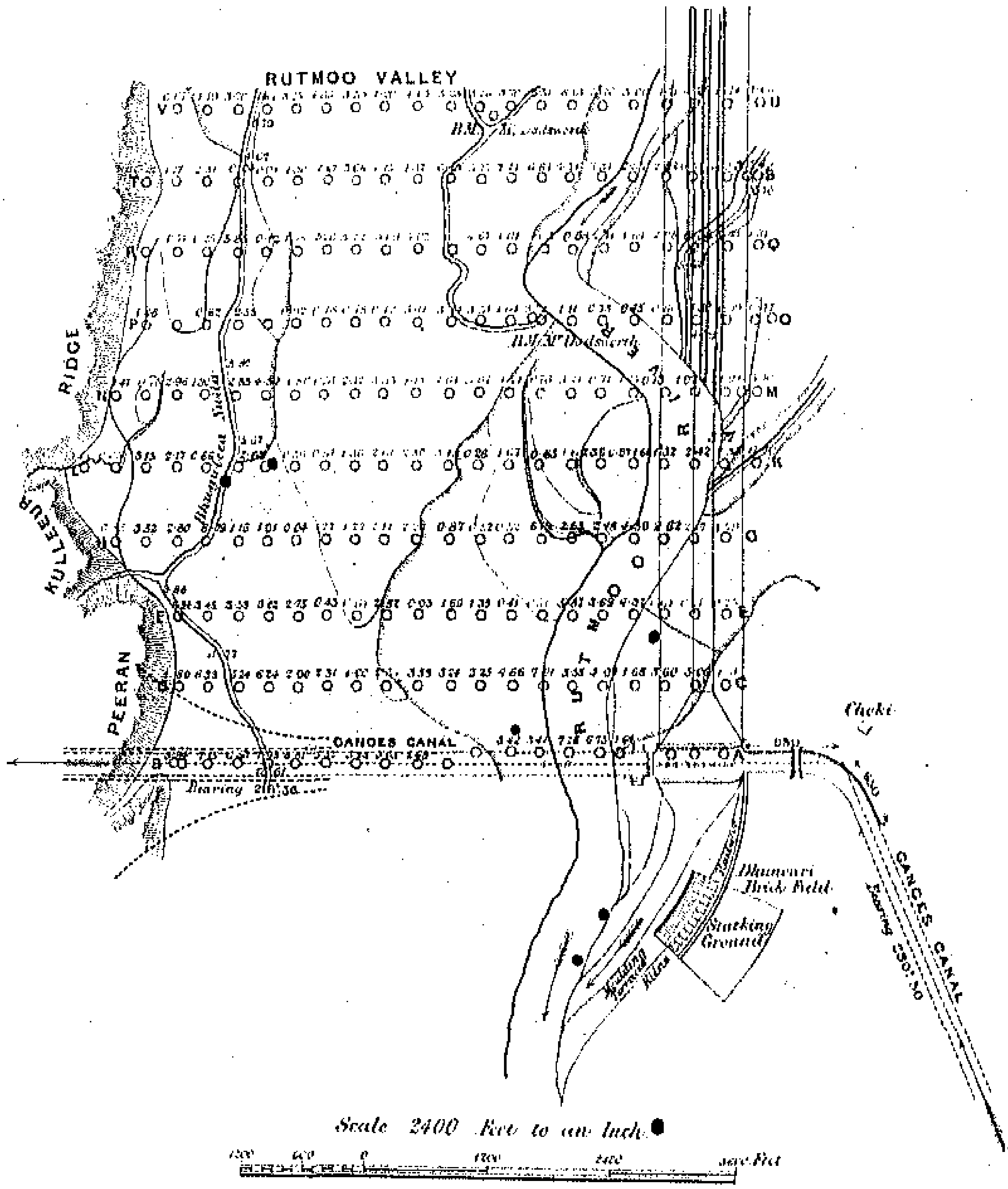
These works consist of dam and inlet thrown across the Rutmoo torrent; a regulating bridge and bridge of cross communication in connection with the canal channel; and revetments with a variety of drainage works appended to them. They are situated between the 13th and 14th miles from the Myapoor regulator, and below the great descent that takes place in the canal bed levels in the region between the Ranipoor and the Puttri torrents. In exhibiting a skeleton of the works which are connected with the Rutmoo River, I shall be able to introduce the details with greater precision.

The following diagram, with the map of the Rutmoo River in the neighbourhood, on the opposite page, will lead to a full understanding of the whole question.

In an early chapter, the causes which determined

DIAGRAM LXV.

DHUNOWRI WORKS SHEWING THE POSITION OF THE MASONRY WORKS WITH REFERENCE TO THE RUTMOO RIVER AND THE METHOD TO BE ADOPTED IN DIRECTING THE STREAM OF THAT RIVER UPON THE MAIN WORKS.



Scale 2400 Feet to an Inch.

The Blue tint shews the extent of inundation in the Rutmoo Valley, with a depth of 10 feet in Canal.
The figures 6·24, 3·58 &c, the depth of water. The Red figures &c, the height of land above the surface level of Canal.
The dark Purple tint shews the 3 Cuts made previously to the rains of 1853, so as to allow the floods of that year to act on the intended bearing.

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the peculiar lining out of the above works, have been described; the inundations on the up-stream side of the torrent, consequent on the absence of works for their prevention, have been especially referred to; it was suggested that a well-managed inlet, with efficient drainage,

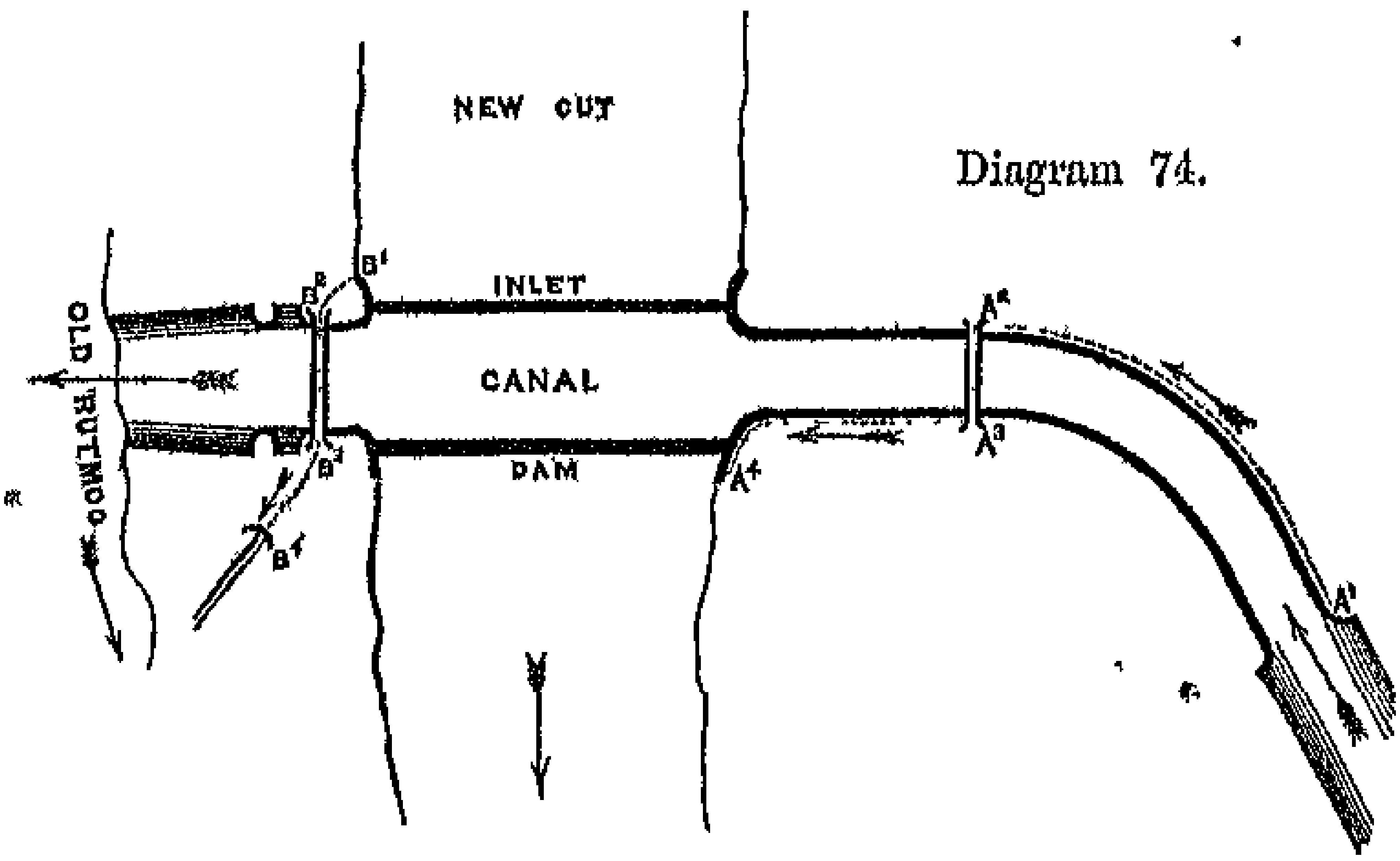


Diagram 74.

might entirely relieve the country from inundation; and that it was possible, when the works were in progress, means might be discovered for perfecting the design in such a way that all the desiderata required should be obtained. I believe this has been done, and that the works as constructed will relieve the country from inundation, and at the same time give a free escape to any water that may either come down the river, or find its way by leakage under the works.

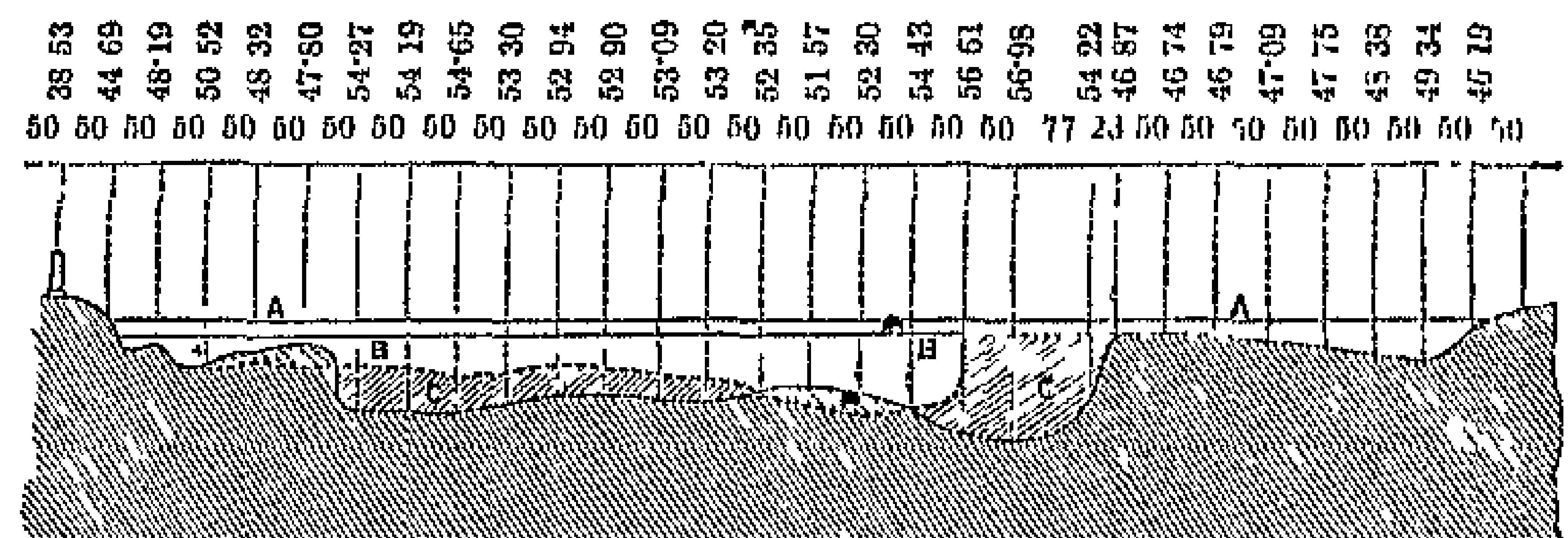
The canal at its intersection with the Rutmoo River, meets it on its own level; the sills of the different works, therefore, are on the level due to the particular slope of the canal bed, calculated on the distance from the zero at the Myapoor regulating bridge.

The Rutmoo, with the exception of a short period of dry weather before the annual rains set in, may be considered a perennial stream, carrying a very small body of

water, but still sufficient to maintain the above character. In the driest weather, and when there is no observable stream, spring water is found immediately below the surface. The area of the catchment basin is 126 square miles; its extreme length may be estimated at 21 miles, six of the most northerly portions of which are mountainous, and the remaining jungle and forest; its average width is six miles. The effective slope upon the works is 8 feet per mile.

The width of the Rutmoo valley at the point where the dam is built is one mile, and the section of the channel of the river itself is shown by the following diagram. This section exhibits the highest observed floods, which took place on the 21st July, and on the 29th September, 1850, and shows the state of the bed of the river, both before and after the floods; offering a fair exhibition of the mutability of the courses of these torrents during the rainy periods.

Diagram 76.



A Flood of 29th September, 1850, 15·77 feet below Zero.
B Ditto, 21st July, 1850, 17·07 feet ditto
C C Earth cut away by Flood of 29th September, 1850

Dotted line represents transverse section of the Rutmoo River before the rains of 1850.
Black line represents the same after the rains of 1850.

By referring to the map, it will be seen that, independently of the torrent itself, which passes on the left, a minor stream runs under the right bank of the valley. This little tortuous nulla, the bed of which is 4·14 feet below that of the Rutmoo itself, is one of those lines of

drainage which I have before described as the usual appendage to all the khadir lands of the mountain torrents. Its bed is, to all appearance, carved out of a hard soil, giving rice cultivation to its neighbourhood; its course is full of springs, and it is marked by "dulduls" or quicksands.

The blue tint on the map represents the area of surface that would be inundated, supposing that the dam was closed, and that the maximum height of 10 feet of water was passing down the canal, without the intervention of a work for confining the volume within its proper channel; or, in other words, supposing that no inlet had been built. The figures represent the depths of water on the blue or inundated surface, and the height of dry land above it elsewhere.

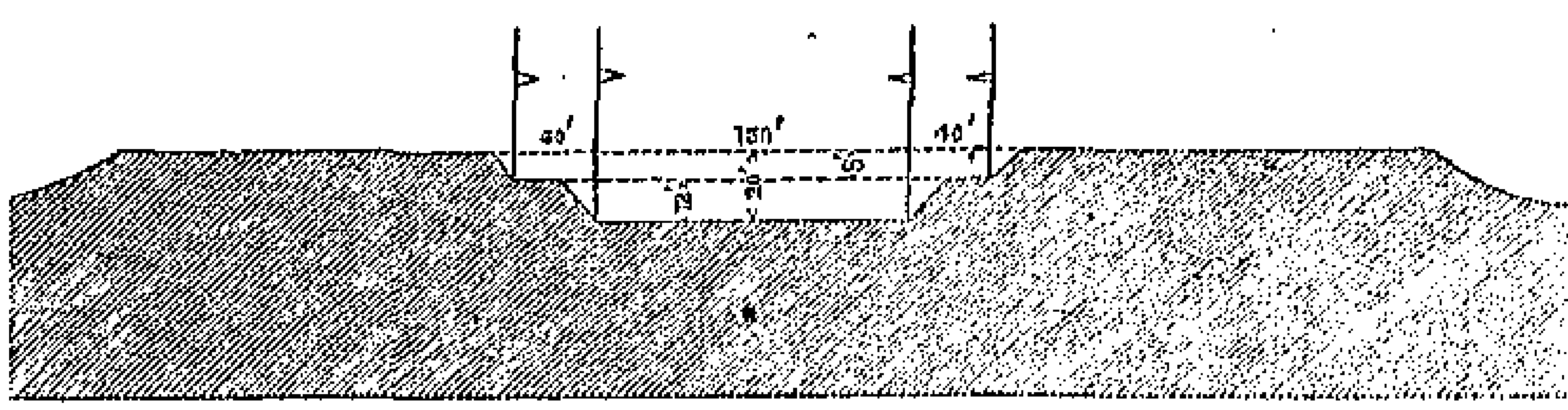
It will be observed that the site of the work is 300 feet to the left of the natural channel of the Rutmoo River, an arrangement which admitted of the annual torrents being passed off during the progress of our operations without interfering with either the excavations or material.

The position in which the works are built necessitates a change in the course of the river, the lining out of which is shown in the map. A system of transverse spurs or embankments, identical with that which has been put in practice at the Puttri, has been carried out on the approach of the new cut to the works; the deep section of the Bhuguleea has been filled in, and cuts have been made from the low ground in its neighbourhood towards the main torrent, for the purpose of relieving the right side of the valley from inundation. The spurs which abut on the right bank will, it is supposed, lead ultimately to the warping up of this side of the valley.

The canal embankments which connect the regulating bridge with the high land on the Peeran Kulleeur ridge, have (with exception of that taken from the channel,

which bears a small proportion to their extent) been made from earth brought out from the deep digging through the ridge. The length of these embankments is equal to 5,000 feet, and the work has been done entirely by the aid of railroads and earth waggons. At the debouche from the deep digging, the esplanade on the top of these embankments has been made of extraordinary width and in a form which is shown in the plan; the object being to cover the Bhuguleea by as great an extent of raised embankment as was possible. The embankments on the right, or those which are more directly opposed to the Rutmoo torrent, have also had increased height and width given to them. The section of the canal channel which lies between the Rutmoo works and the Peeran Kulleeur ridge is as follows:—

Diagram 77.

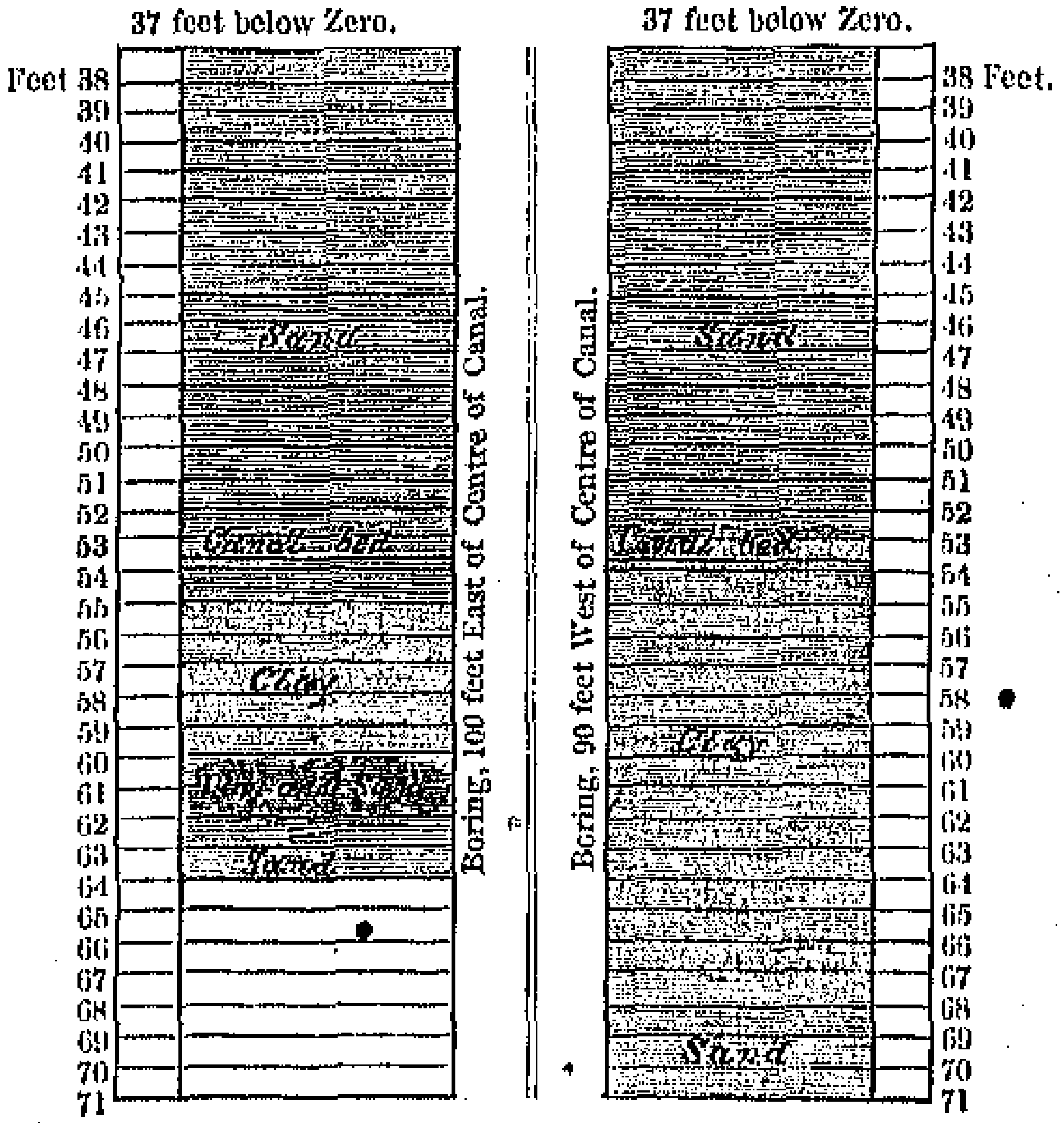


I may observe that, in excavating the channel from A′ to A⁴ (*vide* diagram 74), spring-water was met with at depths varying from 7 to 10 feet from the surface—a circumstance to which I would draw particular attention, from the influence that it had upon the design as connected with drainage. The position of springs with reference to the surface of the country, on the line from the Myapoor regulator to the high land of the Doab at Roorkee, is shown in diagram 166, Chap. X. The result of the boring operations on the site of the Rutmoo works, is shown in the following diagram.

The above outline of the main peculiarities attendant upon the position of the Rutmoo works, will enable the

reader to comprehend the detail which I am now about to enter upon, and to appreciate the difficulties that were overcome, and the final success that attended the assistant engineer in bringing the whole to a completion.

Diagram 78.



The Rutmoo works were commenced in the early part of 1850, under the management of Mr. Thomas Login, who on the completion of the first-class choki, made Dhunowri (the name of the estate in which the works are situated) his head-quarters station. The position of the brick-fields, the connecting lines of railroad, and all economical arrangements regarding the carrying on of the works, were left to Mr. Login's management; their general detail is figured in the map. The proximity of the brick-fields, not only to the works themselves, but to the excavated channel of the new escape from the dam, has been of the greatest possible advantage. The brick soil, although not found in great quantities in the channel excavation, was procurable in the immediate neigh-

bourhood, where it was in sufficient abundance to enable us to maintain a set of puzawas or native brick-kilns, as well as a series of 22 English kilns. The bricks for the latter were made by hand on masonry platforms; and the native kilns were supplied entirely by one of Hall's brick-making machines, the advantages of which have been explained under the head of Materials. After lining out the brick-fields, and fixing the position for the kilns, the brick manufactories were consigned to the charge of the executive officer of materials, who deputed a European overseer for their superintendence.

When the works had been lined out, and excavators had been placed upon them, the first object was to discover in how far the spring-water level might be lowered by taking advantage of the natural declivity upon which the river ran, in carrying a ditch, or trench, on a reduced slope, from the foundations, on a course corresponding with the direction of the current. The natural slope of the bed was 8 feet in a mile. It was supposed that, by giving the bed of a trench a declivity equal to 2 feet per mile, the spring level might be reduced to at least 6 feet, and by these means the laying of the foundations might be commenced at an equal depth below the water level.

The accompanying sketch shows in plan and section, the drainage works that were executed on the above principle; and which, during the whole of the operations, performed their duty most efficiently. The spring-water was reduced 6·25 feet below its natural level, which with the further aid from baling, enabled us to lay in the foundations in some cases to a depth of 10 feet without interference from water; and it secured a system of under-drainage across the line of canal, thereby providing a remedy for the evils of up-stream inundation, which could by no other plan that I can see have been obtained.

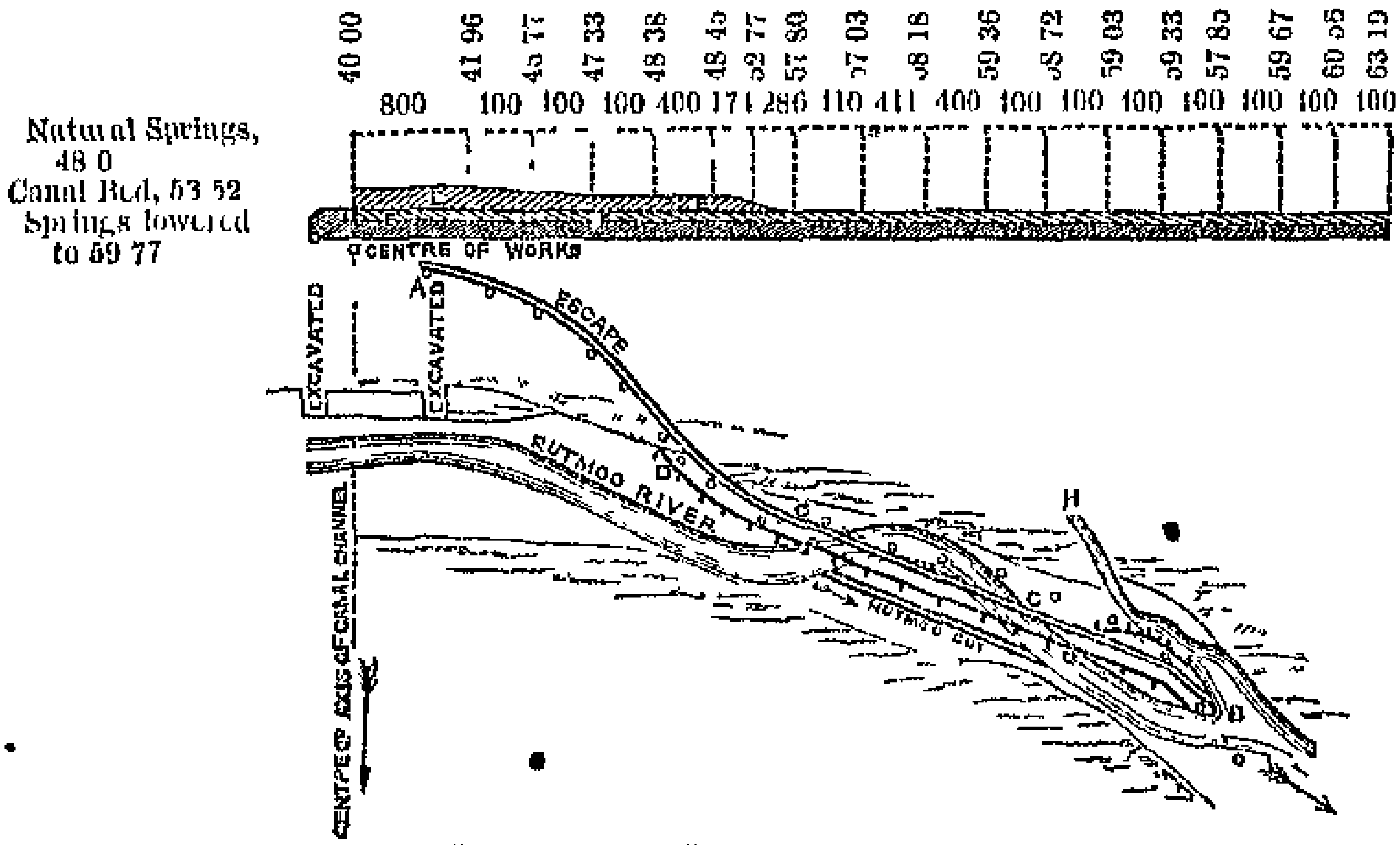
The drainage cut, it will be observed, commenced on

the left up-stream side of the canal excavations for the dam works at the point A. It took the curve upon which the dam escape channel was hereafter to be excavated, and ran for a distance of 6,000 feet to a point in the bed of the river, just below the junction of the Badshahpoor

Diagram 79.

Plan and Section of Dam of the Dhunowli Works

Zero—Floor of Myapoor Regulator.



C C Drainage Cut

D D Bund to protect Drainage Cut.

E E Excavated

F F To be Excavated.

H. Badshahpoor Nulla

Nulla. It was originally excavated on a width of 10 feet, which was (as the foundations increased in depth) gradually increased to 20, and with a slope of 1·5 feet per mile. On this level it struck out on the surface of the bed of the river at the letter B. The cut, in its course down the bed of the torrent, was protected by embankments, strengthened at every 200 feet of its length by short returns or spurs; a similar protective measure was adopted at its point of contact with the Badshahpoor Nulla. The width originally projected was found to be insufficient in sand excavation, where the action of the spring-water had to be contended against; and latterly it was extended to 20 feet, and even to 25 feet, at points where the action of the springs was most energetic.

From the nature of the soil through which the channel had to be maintained, which may be described as sand saturated by springs, it will be understood that this trench was only maintained in an efficient state by constant clearance, and by every attention being given to the regular flow of the water from the foundations: the smallest remissness on the part of the clearing parties, had, in fact, a ready indicator in the state of the high-water mark upon the foundations in progress; and it was quite impracticable to be indifferent to the maintenance of a work on which all progress depended. During flood seasons the protective embankments were necessarily injured, and portions of the cut itself filled up: such events were inevitable, from the very position of the works, situated as they were in the course of the torrent itself. Whatever the difficulties might have been, and however vexatious in the detail of progress, the ultimate success has been most remarkable.

One very great point was gained by the successful maintenance of the drainage line, laying aside the advantages in an economical point of view of obtaining 6·25 feet in depth of building free from the interruptions of water:—it gave us the means of draining the country lying on the right bank of the canal, by masonry channels carried under the canal itself; and it instantly removed one of the greatest of all our impedimenta; it enabled us to relieve the upper side of the Rutmoo from inundation, and to protect to a certain extent the revetments which were connected with the springs, from the injurious action the latter might have upon the masonry work.

Having described the most interesting preliminary period of this undertaking, we now come to the time when masonry work was commenced, and when the curbs or neemchuks for the blocks were laid down. The abrupt curve which the canal takes on its approach to the Rutmoo is tangential to alignments which meet each

other at an angle of 117° 14′ 10″; this curved channel is protected on each side by masonry revetments which abut upon a bridge of cross-communication. Below this bridge the line bears directly upon Roorkee, and the canal proceeds forward to the Rutmoo, between masonry revetments of a similar description to those on the up-stream side of the bridge. The Rutmoo is crossed by two parallel platforms, fitted with sluices for the ingress and egress of the torrent; the platforms having their flanks well protected and built continuously with the revetments which on the up-stream side connect them with the bridge of communication as above noted, and on the down-stream side with a regulating bridge. To the tail of this regulating bridge, flank protections have been given in the shape of ghats, and the whole outline of the works, which will be better understood by reference to diagram 74, has been fortified by the strongest available means in pile and rubble work.

The torrent which crosses the canal at right angles to its course, has, on the plan above described, to enter the canal channel through the sluices of the inlet or work which is built parallel to the dam. This inlet consists of a masonry platform provided with sluices, which at all periods, excepting when floods are running, are closed by gates, the canal water in the latter case being confined to its own channel. It will be evident, that were there in the latter case above noted no means of escape for the stream that comes down the river, or for the water that must to a greater or less degree leak through the inlet, this inlet would act as a dam for the retention of the water, and would be the means of forming an extensive inundation on its up-stream or torrent side. The success with which Mr. Login's drainage cut before described, has acted in lowering the level of spring-water, has enabled me to provide for the above contingency of inun-

dation by carrying subterranean channels underneath the canal, so that when the inlet is closed, and the canal supply is in full vigour, the water that is derived either from the dry weather stream of the torrent, or from leakage, can pass off and escape down the channel of the Rutmoo, without any interruptions leading to inundations. This system of under-drainage has been adopted both in the case above mentioned, and in relieving the revetments from spring-water: the benefits derived from it, therefore, divide themselves under two heads.

1st. The relief of the Rutmoo valley above the canal works, from the water which would collect in large quantities both from canal leakage and from the running stream of the river.

2ndly. The relief of the right revetment from the injurious effects of spring drainage at its foot.

Under the first head, and referring to diagram 74, a drain (or double drain, as it consists of two channels of 7 feet wide each), B^1 B^2 B^3 B^4, with its head B^1 on the up-stream side of the valley, passes under the canal and through the foundations of the regulating bridge. The escape of the drain at B^1 is connected with a cut which carries the water off to the lower levels at a point altogether free from the deposits of the torrent. Under the *second head*, the letters A^1 A^2 A^3 A^4 show the position and direction of a masonry drain which forms a component part of the revetment; it commences at A^1, and is carried on a rapid slope along the rear and at the foot of the right revetment to A^2; the drain then passes under the canal and through the bridge foundations, turning to the right; it then proceeds along the left revetment from A^3 to A^4, at which latter points it joins the Rutmoo River. The detail of construction of these drains will be entered into in its proper place; the general sketch above given will show the advantages that have been taken of

the successful operations in reducing the level of spring-water.

The whole of the masonry works at the Rutmoo, with the exception of a portion of the inlet, are founded upon blocks undersunk from the lowest level to which the spring-water could be reduced. The maximum depth to which these blocks have been sunk below the level of the dam flooring is 20 feet, and the order upon which the engineer worked was to the effect that the further sinking of a block was to cease immediately it came in contact with a well-marked bed of clay below the depth of 12 feet from the canal bed; the depth of 12 feet being considered a minimum.

In entering into a description of the detail and construction of these extensive works, I shall divide them into four items:—

A. *The revetments on the curve of approach up to the dam and inlet flanks, including the bridge of cross-communication.*

B. *The dam with its flanks.*

C. *The inlet with its flanks.*

D. *The revetments on the canal channel on the down-stream side of the dam and inlet, including the regulating bridge and works attached to it.*

A. This portion of the work consists of two lines of revetment varying from 160 to 179 feet in distance from each other; the leading, 250 feet in length, which is in continuation of the alignement bearing on the Puttri super-passage, is 160 feet in width, with the side revetments parallel to each other; the lower, 550 feet, with a bearing equally direct upon Roorkee, is 179 feet in width, with revetments also parallel; the intermediate space is occupied by curves drawn on radii of 661·58 feet and 589·32 feet, meeting the two alignements above described

in tangents. At the tangential point with the lower alignement, is a bridge of cross-communication across the channel. The angle formed by the transition from the Puttri to the Roorkee alignement is, as I have before said, equal to 117° 14′ 10″.

The masonry blocks which form the foundations of the revetments and bridge, are (excepting in those cases where a stratum of clay has been met with) sunk to a depth of 20 feet.

On the division of the work which we are now describing, there are in the

			LENGTH. BREADTH.
Right revetment		71 blocks	20′ × 12′
Left ditto		62 ditto	20′ × 12
Bridge	Bays	6 ditto	21′ × 19½
	Piers	2 ditto	25′ × 17
	Abutments	2 ditto	25′ × 22½.

The dimensions show the measurement of the base; each block, as it will be seen from the plans, being a truncated wedge, the two ends being perpendicular and parallel to each other, the sides being inclined towards the top. Each block rests on a curb or solid frame of timber, upon which the brick-work was raised and allowed to indurate previously to the commencement of undersinking operations. On the completion of undersinking, the interior hollows or wells were filled either with clay or sand, the latter being preferred, if available; in this state they were allowed to stand for as long a period as possible, so as to admit of settlement; the wells were then arched over, and the mass was ready to receive the superstructure. This plan of operations applies to all the blocks, each of which was subjected to the same process. On the lines of revetment the space left between each pair of blocks (to prevent collision in sinking) was equal to from 1½ to 2½, and that between the larger blocks, as in the bridge, was 2 feet. This

space is arched, and in some cases has been merely bricked over previously to the raising of the superstructure. Both in front and rear it is filled by piling driven to a depth of 20 feet, so as to expose as far as possible an unbroken face either to the action of the current in front, or to the thrust of the earth in its rear.

The revetment walls both on the right and left, are on the same design; they offer a curved front to the canal, and are strengthened by counterforts. On the line connected with the under-drainage this wall is still further strengthened by the masonry channels and manholes, which are attached to them. At distances 60 feet apart from each other, and at a height of 10¾ feet from the canal bed, rings, countersunk in the face of the wall, and held in position by strong iron rods which pass through it, are placed on the whole length of the revetment for the convenience of boats and rafts. On the left revetment, where the pressure of the earth acts in thrust on a concave surface, these iron rods are carried back to a distance of 20 and 25 feet, and are anchored in the soil by jhams (tools used in well-sinking), which on the termination of the block sinking were no longer required. The plan of this arrangement, which was designed for the purpose of giving additional strength to the revetment is shown in Plate XXV. Sheet 5, Figs. 1 and 2. From the entrance into the masonry channel in the up-stream direction, down to the bridge, the height of the revetments is 12¼ feet; below the bridge it is 15¼ feet: a parapet wall 2¼ feet in height runs along the whole.

The bridge consists of three bays of 55 feet each, each bay having a masonry flooring, and being 20 feet in height from the soffit of the crown of the arch to the flooring beneath it; the design of the elevation is plain, and the roadway is 24 feet above the bed of the canal.

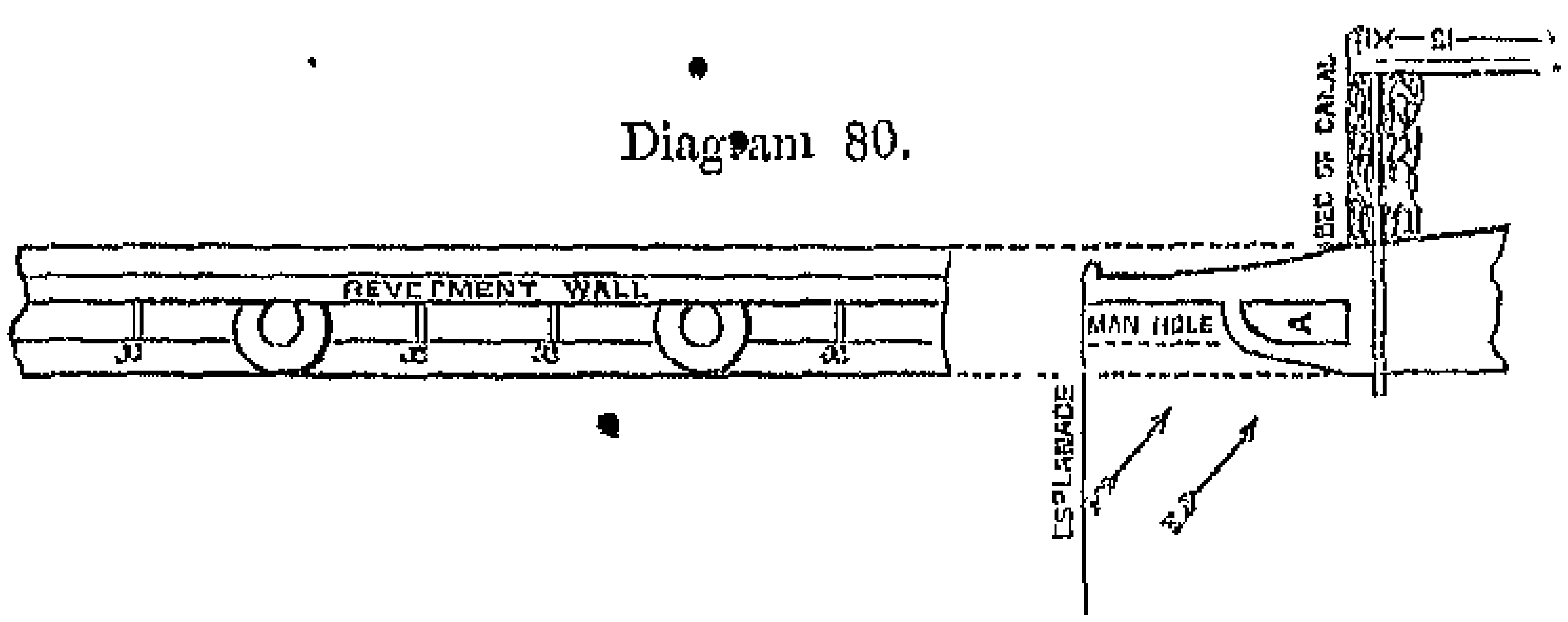
Flights of steps for the convenience of access to the water from the upper levels, have been built on both sides of the canal in immediate contact with, and on both the up and down-stream sides of the bridge.

The foundations of the revetments and flooring of the bridge are protected by lines of sheet piling, driven at a distance of 10 feet from the foot of the masonry; the space between the piling and the masonry is filled with bolders or river-stone to a depth of 5 feet; and the whole is covered by sleepers or rafters of wood, for the purpose of retaining the material in position. Advantage has been taken of the peculiar construction of the foundations, and their consisting of separate masses, to add still further to the strengthening of this apron work by keying the front piling to the rear of the blocks by woodwork as shown in Figs. 1 and 2, Plate XXV. Sheet No. 5.

By referring to the position in which these curved lines of revetment are built, and by considering the nature of the soil, and the state of the springs in the land through which the excavation was carried (*vide* diagram 166), it will be understood that the canal channel which runs transversely to the direction of the spring current has its right revetment opposed to it in all its activity, whilst the left, which is cut off by the intervention of the channel, is in a great measure relieved from its influence. It was for the purpose of remedying this defect, that the masonry drain, the direction of which is shown by the dotted lines and letters A^1 A^2 A^3 and A^4, in diagram 74, was designed. This drain, which is $2\frac{1}{2}$ feet in width, commences at the point marked A^1, is carried on a rapid slope along the foot and at the rear of the right revetment, until it meets the bridge at the letter A^2; the drain then passes under the bridge floorings to the opposite side of the canal, and at the letter A^3 turns to the right, pursuing its course along the foot of the left revetment, and escap-

ing at the point marked A^4 into the bed of the Rutmoo, by an open sluice connected with the tail floorings of the dam. The section of this drain is sufficient for the purposes of silt clearance, and at every 60 feet in length, or intermediately between each counterfort, a well or man-hole is constructed from the upper levels, and continued perpendicularly through the arch of the channel, not only for facilitating the clearance out of the channel itself, but for affording free ventilation. On the passage of the drain channel under the bridge, similar cylinders or man-holes are carried vertically through the piers and abutments, and are provided with lateral ventilation, the upper orifice being closed by a stone slab, for the purpose of completing the bridge roadway. The great object of this drain is to relieve the right revetment from the action of the springs—of that especially which exerts a downward pressure upon the masonry, and which on the mountain, or right side of the canal, is more conspicuous than elsewhere. Although the plan and section of this drain, as connected with the revetments, are drawn in Plate XXV. of the Atlas, it will be convenient for the purposes of explanation to introduce them in diagram.

Diagram 80.



x x x are slits through the arch and wall of the foot channel or drain A, as in section. These slits are not more than $\frac{1}{4}$ or $\frac{1}{2}$ an inch in width, and they are covered in the rear with pieces of broken brick and loose rubble,

through which the spring-water can freely percolate, and at the same time offer as great an impediment as possible to the admission of silt; the rear of the wall is then filled in to the height of the esplanade with soil. By any person acquainted with agricultural drainage, as it is practised in many English counties, the design will be recognized as *a mere modification of the rudest species of under-drain channel*, where after excavating a ditch, the lower part of it is filled with broken stone in angular fragments, over which the earth is thrown; the under-drainage being effected by percolation through the stony stratum. I presume that, after a time, this species of drainage becomes interrupted by deposits of impervious matter, which by occupying the open spaces between the angular masses, checks and ultimately stops the passage of water, and that the only remedy is a periodical relief by either cleaning or renewing the fragments,—an operation, in the case of land drainage, I should imagine, leading to great trouble and expense; but in *that of the Rutmoo revetments, of comparatively minor* importance, from the modified form in which it has been practised.

In laying out the line of drain underneath the bridge, or that part of it which lies between A² and A³, it was found necessary to deviate from the direct alignement on which it was originally designed. The change from a direct to a tortuous course is by no means an improvement, either to the free passage of the water, or to facilitating clearance from silt.

In conclusion, I may observe that, judging from the perpetual discharge of water from the escape opening at A⁴, and the constant gurgling of running water, as heard *through the man-holes* on the whole *length* of the revetments to which the channel is attached, the drain is acting very efficiently.

B. This includes the dam proper, or the work for relieving the canal channel during the rains from the torrent, which gains admission through the inlet; it also acts at other periods of the year as a regulator to the canal supply.

The work under the division to which I have confined myself in the present detail, consists of a platform carried across the bed of the Rutmoo River, protected on each flank by revetments, which are in continuation of those described under the head of A.

This work is built upon blocks of the same pattern as those before described, viz., truncated wedges, whose ends are parallel, and whose sides slope inward to the top:—

				Area of base.
The platform rests upon		25	blocks	$30' \times 30'$
Up-stream right wing		2	„	$\frac{20\ 1' + 15'}{2} \times 12{\cdot}6'$
„ left	„	4	„	$\frac{18{\cdot}4' + 7{\cdot}8'}{2} \times 12{\cdot}85'$
Down-stream right wing		2	„	$19' \times 12'$
„ left	„	2	„	$19' \times 12'$

Their construction will be understood by reference to the Atlas; the details in adapting them to the superstructure are exactly the same as those before described for the revetments. It will be observed, however, that additional width of platform, both to the front and rear, has been obtained by corbels and projections, so as to increase the width from 24 to 27 feet, the detail of which is given in the plan.

The superstructure of the up-stream wings and flanks of the dam corresponds with that of the revetments, of which they are in continuation; they are raised 15 feet above the flooring of the dam, independently of the parapets. The flanks are pierced by a passage constructed in the form of an inclined plane, on a slope of 1 in

5, which gives the means of approach to the dam from the esplanade levels. The down-stream or tail wings are built with an inclination towards the axis of the bed of the river. Their superstructure, which is 6 feet in height from the flooring of the dam, is connected with the flanks and the esplanade level by a series of steps.

The dam itself consists of 47 sluices of 10 feet in width, with their sills flush with the canal bed, separated by piers of 3½ feet. The above are flanked on each side by five sluices of the same width, but having their sills raised to a height of 6 feet, with intermediate piers of the same dimensions as those in the centre sluices. On the extreme flanks are platforms raised to a height of 10 feet above the canal bed, and corresponding in height with the rest of the piers. These elevated platforms, which are 17 feet in length, are connected with the revetment esplanade by the inclined planes which I have before described as carried through the flanks of the dam.

The amount of waterway, therefore, through the sluices, up to a height of 6 feet, is equal to 470 feet in width; to a height of from 6 to 10 feet, it is increased to 570 feet, and when flood water rises above that height, the water passes over the full expanse of the masonry, which is equal in width to 800 feet.

For the ten sluices on the flanks, the closing and opening will be left entirely to sleeper planks for which grooves are fitted to the piers. For the centre openings a form of double sluice-gate has been adopted, the plan of which will be understood by reference to Plate XXV. of the Atlas. A gate of 5 feet in height, moveable on lower side pivots, is placed on the rear of the sluice opening; this gate drops forward and towards the canal stream, and when it rests on the flooring, is held in position by a bolt worked from the top of the pier; by removing the bolt, the gate is relieved from its prostrate position, and is

raised so as to admit of water to a depth of 5 feet passing down the canal. In front of this small gate is a large one, equal in height to the pier itself, moving also on lower side pivots, and capable only of falling to the rear.

The working of these double gates is as follows:—When the canal is full, the rear gate is held down on the floorings in the prostrate position above mentioned, by the bolt, and the large gate in the front is maintained in a vertical position so as to retain the canal supply. On the occurrence of a flood, these large gates are relieved, and are permitted to fall upon the flooring, thereby giving an open and uninterrupted passage for the water.

The floods having passed, the rear small gate is relieved by pulling up the bolt, and the gate is raised partly by its own specific gravity when it comes in contact with the canal, and partly by manual labour; and on its attaining a vertical position it is kept so by the front pressure of the water. The height of this gate being 5 feet, an immediate supply can be admitted into the canal equal to that extent; in the meantime the apparatus for raising the front gates is put in requisition, and this is considerably aided by the back-water standing on the rear gates. The closing of the larger or front gates admits of the full supply being passed down the canal. The small or rear gates are then dropped, restored to and fixed in their recumbent position by the aforesaid bolts. When the canal is in full supply, therefore, the smaller gate is out of use; its main object being to expedite the admission of water to a certain extent into the canal, during the operation of raising the large gates.

The design is an ingenious one, and is due to Mr. Login, although its details have been worked out to completion by Captain Goodwyn, to whom the invention of the bolt for holding down the rear gate is due. The

scheme has been experimented upon, and the only difficulty that offered itself was, in maintaining the small gate in a recumbent position, which its want of weight prevented when immersed in water. Captain Goodwyn's bolt appears to remedy this inconvenience, but it will require a good deal of practice before the working of the apparatus is satisfactorily developed, especially that part of it which is connected with the large gate, the weight of which is considerable. The details of the apparatus for raising the gates and keeping them in position are fully represented in Plate XXV. of the Atlas.

It must be understood that the mountain torrents with which the works are connected, carry in their waters material of all sorts, collected in their passage through extensive regions of forest. Trees of the largest size, root and branch, are frequently thrown down, and carried with an overwhelming velocity along the course of the river. Grass, branches, and hewn timber, left in the forests after the carting season is passed, are swept away, and gathered in heaps on any obstruction that offers itself to the opposing current. The effect of the onward progress of this collected mass is to carry away the object that causes the obstruction with it; and to any work like a dam with suspended self-regulating gates, or with attached and projecting apparatus it would be fatal. The great object, therefore, with works of the sort which I am now describing, is to adapt the sluice-gates in such a way to the openings, that they may be instantly removed, and self-placed in such a position that they may offer no impediment whatever to the current. The gates which I have described, fall, it will be observed, upon the floorings, and the flood passes over them. The whole work is, in fact, on the falling of the gates, left perfectly naked, without any further obstruction to the passage of the water than that offered by the piers.

The protective arrangements for covering the foot of the revetments, which I have before described, are continued *round the up-stream flanks of the dam, along the* face of which is a similar line of apron, formed by piling and box-work filled with bolders, the whole mass being strongly held together by sleepers. The apron which has been thus described has a slope inwards towards the canal of 1½ feet, and it is intended to act not only as a bar to the interference of the water with the foundations, but to protect the wall from the effects of the current as it sweeps along at its foot.

On the down-stream side of the dam, a platform of box-work, filled with river-stone, extends to a width of 43½ feet from the masonry flooring; this is held in position by double lines of 20-feet piling, strongly clamped *together by sleepers fastened on to the upper surface, the* slope of which is 2¼ feet on an incline down stream. To the whole of these protective works the greatest attention has been paid, and as far as I can judge from having seen them both in progress, and after completion, they appear to be excellent. The flanks of the tail are protected by open pile-work driven in prolongation of the down-stream flank walls.

C. Embraces the inlet or platform which is built across the channel of the Rutmoo, parallel and opposite to the dam, for the purpose of receiving the floods into the canal, as well as for retaining the canal supply in its own channel; *to this is added* flanking defences similar in many respects to those attached to the dam.

The work is, with the exception of the greater portion of the inlet itself, founded upon blocks of the same pattern as before. They come under the following denomination:—

Platform of inlet . .	3 blocks	$30' \times 19'$	{ in addition to plain foundation.
Up-stream, right wing .	3 "	$23' \times 12'$	
" " .	1 "	$17' \times 12'$	
" left wing .	3 "	$23' \times 12'$	
" " .	1 "	$17' \times 12'$	
Down-stream, right wing	2 "	$\frac{20{\cdot}1' + 15'}{2} \times 12{\cdot}6'$	
" " .	4 "	$\frac{18{\cdot}4' + 7{\cdot}8'}{2} \times 12{\cdot}85$	

Their construction will be understood by referring to the Atlas; and the subordinate work necessary for the reception of the superstructure is in every way similar to that before described.

The inlet is, with the exception of one block on the left, and two on the right flank, occupying a space of 94 feet in length, built on running lines of foundation wall, laid to a depth of 10 feet, or to the extreme depth to which the spring-water could be reduced. This was a very satisfactory result of the drainage operations; it led to great saving of expense, and to a more efficient foundation; the running line of curtain wall being free from the interstices which are an inevitable consequence of using blocks, and which, by leading to leakage, are evils of no inconsiderable importance. This 10 foot foundation which is in the form of two parallel walls 3 feet thick, and situated 13 feet apart, with cross walls of 3 feet in width at each 23 feet of its length, rests upon clay. It will be understood that the fact of there having been three blocks sunk was perfectly accidental: these blocks would not have been introduced had Mr. Login been aware that he could obtain so great a depth as 10 feet by a reduction of the spring level.

The superstructure of the down-stream wings, or those on the canal side, correspond with the revetments of which they are a continuation; their height is 15 feet—equal to that of the walls attached to the dam. The

flanks of the inlet are also similar, having inclined planes on a slope of 1 in 5 for giving access to the inlet platform from the higher levels of the esplanade. The up-stream wings, or those which flank the torrent on its approach to the works, are placed in an oblique position, inclining outwards from the axis of the river; they are 91 feet in length, and raised to a height corresponding with that of the revetments. On the right, the wing is *pierced by two drain-heads, each of which is 7 feet in* width, and $5\frac{1}{2}$ feet in height, measuring from their floor to the soffit of the keystone. The sill or flooring of these drains is on a level with that of the inlet. To these drain-heads, which are connected with the under-channels for relieving the country from inundation, drop-gates, and the necessary apparatus for opening and shutting them, are attached: this apparatus, in the shape of windlasses, bitt-heads, &c., is in the rear of the revetment wall, and secured by its position from accident.

The inlet consists of twenty-nine centre openings of 10 feet in width each, with their sills raised 2 feet above the canal bed; on each flank of these centre openings are fourteen of similar width, the sills of which are raised 6 feet above the same level; the extreme flanks are terminated by a platform 17 feet in length, which is raised 10 feet above the bed of the canal, or equal in elevation to the piers. This flank platform is connected with the upper esplanade levels by an inclined plane as before described. The thickness of the piers is, as in the case of those of the dam, $3\frac{1}{2}$ feet; they are fitted with vertical grooves for the admission of sleeper planks, bitt-heads, and the necessary apparatus required for the movement of the gates. The tops of the piers have countersunk rests cut into them, in which planks are laid from pier to pier, *so as to form a line of communication across the*

sluice openings: these are in every respect similar to those in the dam.

The centre sluices have gates moving on lower side pivots, which fall down-stream to the torrent; they are 8′ 8″ in height, and constructed agreeably to the detail shown in the plan. It is supposed that the pressure of water running in the canal will, with certain aid from the bitt-heads, hold these gates in position; leakage being prevented by the usual simple means adopted by the native establishment, of applying grass, wisps of straw, &c. Counter-pressure superior to that on the canal side would necessarily force the gates open; and as flood-water would give this increased counter-pressure, it would act of its own accord in relieving the sluices from the obstruction caused by the gates. This species of gate, applied as it is to the Rutmoo inlet, acts as a self-regulator, and will, I doubt not, be found to be efficient. The twenty-eight side openings or overfalls have no gates; they will be regulated by four planks of 12 inches in depth each, on the same plan as is practised on the Jumna Canal Works. These planks are raised at the ends by hooks run through an iron strap, which forms a loop at each extremity. It will be observed, that none of the sleeper apparatus is required until the depth of water in the canal exceeds 6 feet.

Before closing the account of the dam and inlet, which are the leading features of the works on the Rutmoo River, I must draw attention to the longitudinal profile as given in diagram 3, fig. 3. By this it will be seen that the effective slope of the torrent at the point where it is intersected by the canal, is equal to 8·23 feet per mile, or 1·87 inches per 100 feet in length. Now, looking transversely to the line passing through the inlet, canal channel, and dam, we find that the length occupied by these works is equal to 304·5 feet, or that the longitudinal

axis of the inlet is at a distance of 304·5 feet from that of the outlet. With a slope, therefore, of 8·23 feet in the mile, the sill of the inlet ought, that it may correspond with the slope of the bed of the river, to be $1{\cdot}87'' \times 3{\cdot}045$, or 5·69 inches above that of the outlet. There is an advantage, however, in maintaining the sill of the inlet at a moderate height, as it enables us to reduce the extent of sluice area, and by so doing to give us greater facilities for adapting the means of opening and shutting the gates. An increased velocity of current at this particular point, so as to expedite the passage of silt and alluvial matter through the canal channel, may possibly be an advantage. At any rate, but chiefly with reference to the effective slope above mentioned, and to the desire of reducing the height of the sluice openings, the sills of the inlet are raised 24 inches above the horizontal level; that of the dam being flush with the above level, with the exception of a masonry step of ten inches which the piers for the gate require. I am by no means certain that it may not be found advisable hereafter to raise the sills of the dam, by which two advantages will be gained; first, a reduction to the dimensions of gate necessary for opening and shutting the sluice; secondly, a fixed channel to a depth equal in amount to that of the sill level, in which a supply of water will pass down the canal irrespective of sluices. At the Dhunowri works, however, we have to observe the effects arising from two large volumes of water meeting at right angles in the centre of the confined area lying between the flanks of the dams; that from the torrent passing with a velocity due to a slope of 8·23 feet per mile; that from the canal channel, which will include the drainage from all the inlets below the Myapoor regulating bridge (relieved only by the Kunkhul escape, and that attached to the Bahadoorabad mill channel), running with a velocity due

merely to 1¼ feet. I may observe, that the anticipated consequences may be a retention on high levels of that volume which flows with the least velocity; in other words, that the rapidly running torrent which crosses the canal channel will retain in a measure the body of water that comes down the canal; that this latter will find a vent, with considerable action on the works round the left or north flank of the dam, with a proportionate regurgitation in the area lying on the opposite side of the canal channel, and under the left or north revetments of the inlet. It is impossible to say to what extent this action of the water may lead to the deposition of silt; but in anticipating the action as certain in a greater or less degree, I have strengthened in every reasonable way the foundations of the works at the particular points referred to, and I have raised the flank revetments to such a height, that I believe they may be looked upon as secure from any contingency of accident arising from the meeting of the two streams.

The whole of the works attached to the inlet, and which I have described under the division C, are protected by aprons, consisting of piles driven 20 feet deep, in close lines, at distances (as represented in the plan) from the foot of the walls of the revetment, and in advance of the front and rear of the inlet; the intermediate space being filled with box-work and river-stone, covered with sleepers well clamped down to the piling. The aprons on all occasions slope outwards from the work to a perpendicular depth of 18 inches. The terminations of the wings on the up-stream side towards the torrent are well protected by open piling, connected by transverse ties or transoms.

D. Under this letter we arrive at the regulating bridge; its connection with the dam and inlet; and

the uses made of its foundations for the purposes of under-drainage.

The whole of these works are founded on blocks, which come under the following denomination :—

			Area of base.
Regulating bridge . .	9	blocks,	$32' \times 22'$
" " . .	2	"	$32' \times 15'$
Up-stream right revetment	4	"	$18' \times 12'$
" left " .	4	"	$18' \times 12'$
Down-stream right " .	2	"	$\frac{28' + 15{\cdot}2'}{2} \times 13{\cdot}6'$
" left " .	2	"	$\frac{28' + 15{\cdot}2'}{2} \times 13{\cdot}6'$

The method of adjusting the substructure with reference to these blocks has been before described.

The superstructure of the up-stream revetments, which are the connecting walls between the flanks of the dam and inlet and the up-stream side of the regulator, is similar to that on the down-stream side of the bridge of cross communication, which lies on the left of the Rutmoo River; it corresponds both in height and dimensions. On the down-stream side of the regulating bridge, the sides of the canal channel are protected by sweeping lines of masonry wall, enclosing flights of steps or ghats, which give access to the canal water from the berm. The height of these walls is equal to 12 feet; they are in connection with the bridge, and the sweep, which is in immediate contact, is combined with a flight of steps, affording the means of approach from the levels of the berm to the channel for under-drainage.

With exception to the width of roadway, which, in the present case, is only 22 feet, the regulating bridge is precisely the same both in extent of waterway (viz., 10 bays of 20 feet in width each), and in apparatus for opening and closing, as that of the Myapoor regulator; a description, therefore, of these details becomes unnecessary. The bridge wings, however, are adapted to the

local requirements of the work: on the upper side they are of the usual dimensions; on the lower, they are somewhat extended in length, to meet an increased width of embankment as well as a ramp, which runs in continuation of the towing-path from the Solani aqueduct. Plate XXV. of the Atlas exhibits this in its fullest detail.

Under the head of C, and when describing the right up-stream wing revetment, I drew attention to the drain-heads which are pierced through that part of the work, and to the regulating arrangements in the shape of shutters, &c., that were connected with it. These drain-heads are the openings for the admission of the Rutmoo stream, and for any water that may escape through the inlet during the dry weather; they are, in fact, the openings by which it is hoped that we shall escape from inundation on that side of the torrent which is above the works. The heads which I have before described, as 7 feet in width each, with a height from the floor to the soffit of 5½ feet, are connected with arched passages, which leave the revetment at right angles to its face. These passages are separated by a pier 4 feet in width, and they descend on a rapid slope of 9 feet in a length of 120·86 feet to a flooring, situated, at the point of contact with the abutment, at a depth of 7 feet below the level of the canal bed. From this point the flooring is carried under that of the bridge on a horizontal level, until it terminates in the excavated channel, the width of which is 20 feet, with a slope of 3·44 feet per mile. These passages meet the bridge alignement by a curve tangential to the angle of approach; they leave the bridge on a similar curve after passing under the canal channel, and continue on a tangential line to a distance of 159 feet, in which space the canal embankments lying on the left

are passed: they then open out into the channel excavated for the purpose of carrying off the water.

These under-drains are approached both on the up and down-stream sides of the bridge, by passages built in connection with the revetments, access to the channels themselves being gained by flights of steps. Man-holes or cylindrical wells of two feet in diameter, are carried perpendicularly through the piers and abutments, the tops of which are on the bridge roadway, being covered by stone slabs; whilst side openings give the means of ventilation. To each pier and abutment two of these holes are given; and it is supposed that they, together with the flank passages, will provide sufficient means for clearing the channels from deposits.

The plan for using these channels ought to be as follows:—During floods their heads would be entirely closed, the shutters would be down, and no access to the flood water would be permitted. It is only at periods when the Rutmoo is not in flood, that these drains would be brought into use; during this period, the shutters would be raised, and the mouths of the channels would be kept free and open. The working parties of Beldars attached to the regulator, would do all in their power to conduct the stream of the river, (which during the dry season is moderate), as well as water coming from the works, to the mouths of the drain; rubbish in the shape of branches and trees, ought to be prevented from approaching the drain head, and it might be necessary as a greater preventive to its admission, to guard the openings by iron gratings.

It is indispensable that during floods the drains should be thrown out of use, otherwise, should no worse accident happen, they will inevitably be choked up. Whether it may be convenient at any time to attempt a scour, by

forcing a current of considerable volume through these drains for the purpose of cleansing, may be left for after consideration; that they will require periodical clearances, is certain from the disposition of the slopes of the flooring, but it is hoped that whether by the means of access now given for the object of clearance, or whether by occasional scours of water passed off from the canal, these channels will be found capable of performing the duties for which they have been designed. I need hardly advert to the extraordinary value that the efficient maintenance of these channels as free water-passages possesses for benefiting the works at this particular point, and the influence that it will have on the salubrity of the neighbouring country. I have no hesitation in recording my opinion here, that the success which attended Mr. Login's measures for drainage on these works, and which enabled me to carry out the design for the under channels which I have above described, is amongst all the extensive and difficult operations which have characterized the execution of the Khadir Works, that one of all others which has given me the greatest satisfaction, and which has relieved me from one of the greatest difficulties.

Having thus described the whole of the works at the Rutmoo River, in a way which with the plans, I hope, will be sufficiently clear, I will now give as concise an account as possible of the cost, material used in the construction, and the rates as charged by the executive engineer.

I have before mentioned that the ground both with reference to the works themselves, and to the brick fields in the neighbourhood, was entirely laid out by Mr. Login, to whom, as having to superintend the construction, free liberty was given to adapt them to his own convenience;

the ground plan is shown in diagram 75. The brick-making was under Mr. Finn, the Executive Officer of the material department.

The sizes of brick used were $12'' \times 6'' \times 2\frac{1}{2}''$, and $9'' \times 4'' \times 3''$, the former being burned in the English, and the latter in the native kilns: the latter I have before said were made in one of Hall's brick-making machines.

The whole of the Rutmoo works are built with brick, with the exception of the massive parts of the foundations, in which bolders brought from the passes in the Sewaliks are used. The heavy material placed in conjunction with the piling and box-work, for the protection of the works, was of river stone. The lime was of the best description, and similar to that used invariably in the Khadir works, made from lime rock either burnt in the Deyra valley, or from lime bolders collected in the bed of the Ganges.

The proportions of material used in cement were as follow:—

Mortar		1 Stone Lime. 2 Soorki.
Plaster	Inlet and Dam Piers	1 Stone Lime. 2 Soorki.
	All the rest of the Work	3 Stone Lime. 2 Soorki.

The whole being finished off with a colour of 7 parts of Stone Lime to 1 of Soorki.

The total amount of material is shown in the following table, to which is appended the rates of the different species of work which has been executed:—

	Cubic Feet.
Total Content of Masonry	1,496,463

MATERIALS EXPENDED.

Bricks, 12″ × 6″ × 2½″	12,134,613
" English Machine . .	813,852
Bolders	126,125 maunds.
Thama	26,964 cubic feet.
Stone Lime	208,981 " "
Soorkee	397,906 " "

	RS.	A.	P.	
Plain Masonry . . .	16	13	0	per 100 cubic feet.
Brick on Edge Masonry	20	9	5	" " "
Arch Masonry . . .	19	6	0	" " "
Plastering	2	3	7	per 100 square feet.

The grooves throughout the works at the Rutmoo, have been protected by slips of stone, and in all cases where the working of the gate or sleeper apparatus was likely to injure the masonry, stone has been used: the material is brought from the quarries in the Agra district, and is altogether of a superior description to the Sewalik rock. In conclusion I may observe that the whole of the brick-work is stuccoed on its external surface with a thin layer of lime cement.

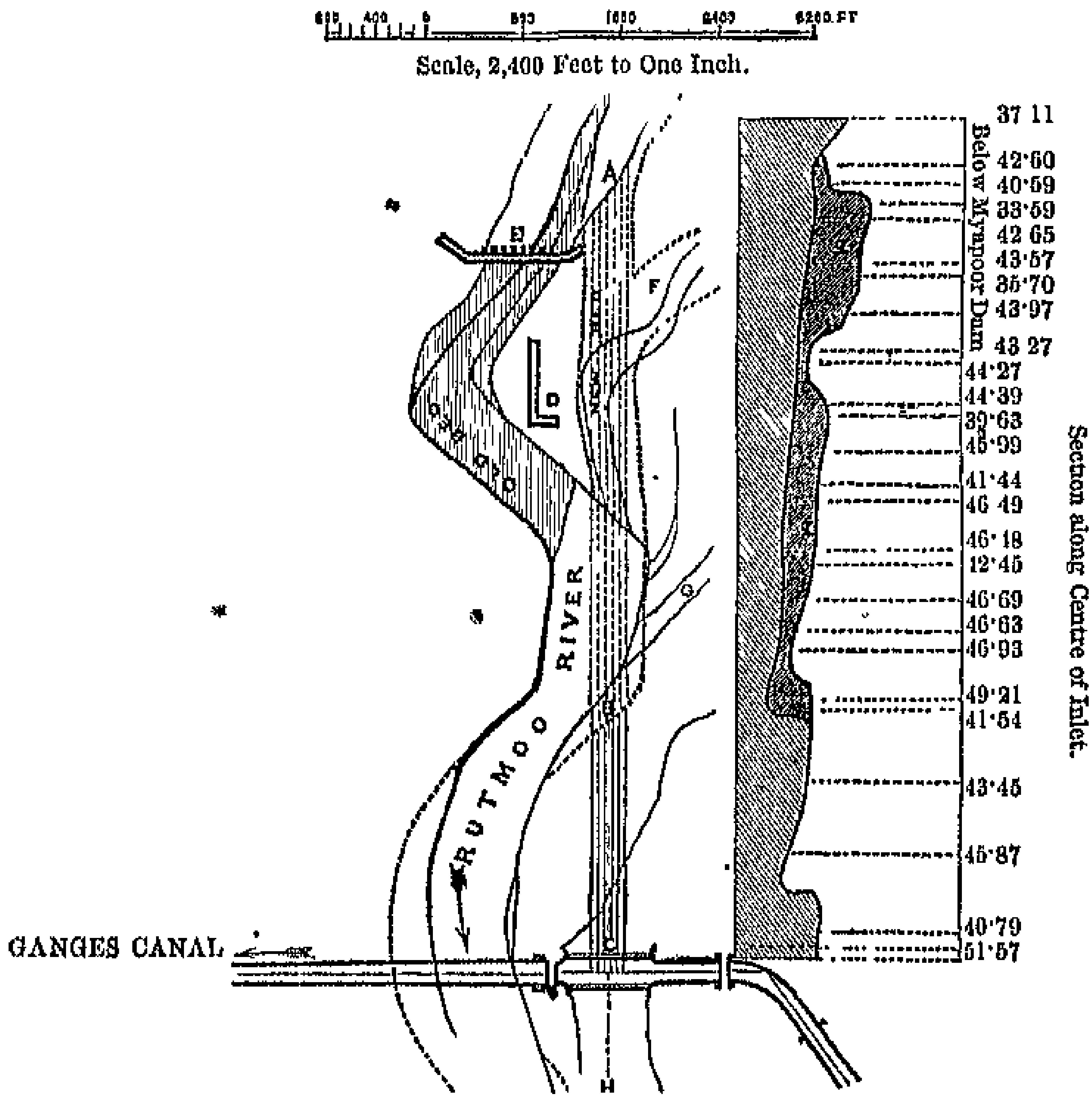
Previously to the rains of 1852, it was considered desirable to commence operations on the river, in progress towards its change of course upon the works. For this purpose three cuts represented in *diagram* 81, were made in prolongation and parallel to the axis of the works across a bend in the river.

The effects after the rains of 1852 are shown on the face of the diagram. The arrangements were well matured, and so far as the straightening of the course of the river was attempted, they were successful. In 1853, and in preparation for the floods of that year, the masonry works being sufficiently advanced to admit of water being passed over them, the three cuts above alluded to, were prolonged to the inlet, or in the

diagram from B to C. At the early part of the season, there was some difficulty experienced in persuading the flood water to leave its old channel, and to follow the direct course which was opened out for it. This partly

Diagram 81.

Showing how the arrangements made prior to the Rains of 1852 affected the course of the RUTMOO RIVER.

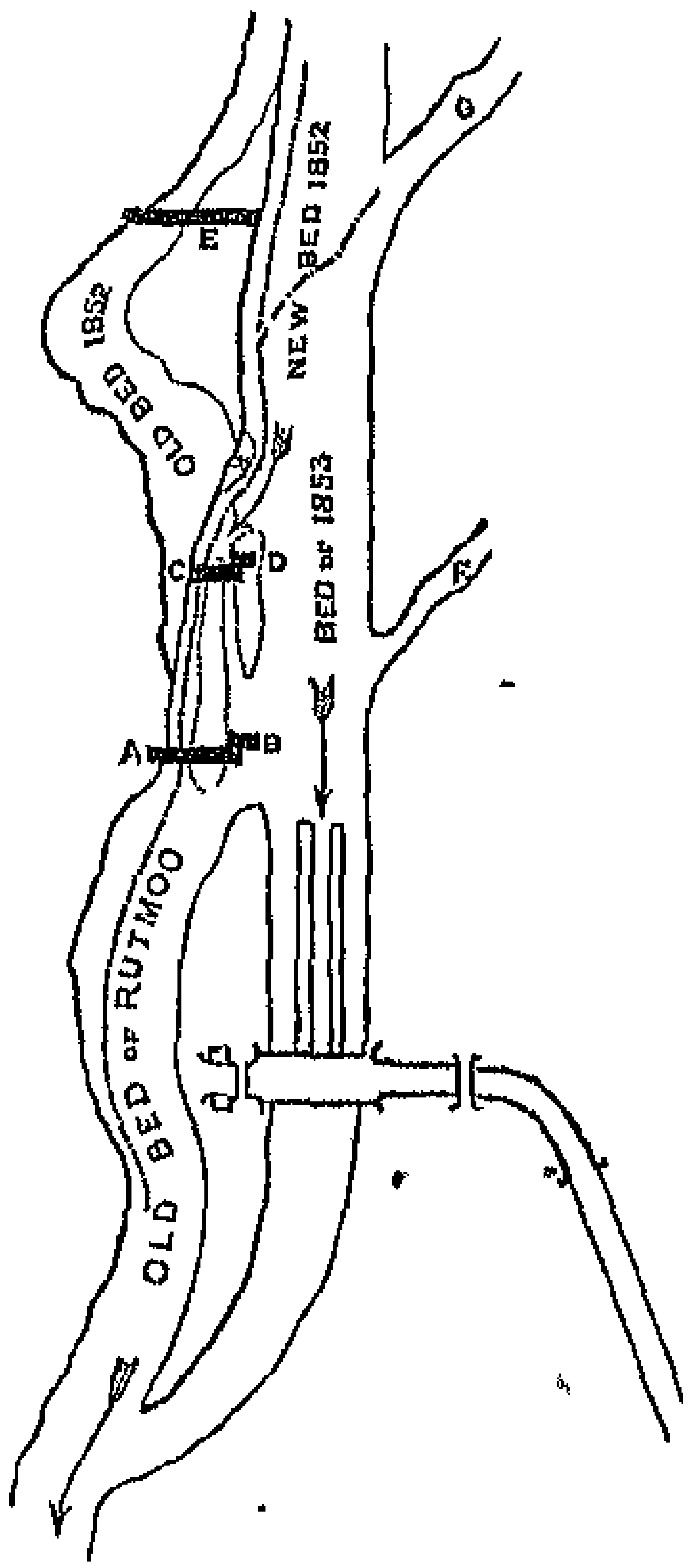


D. Bund to direct Course of River. E. Bund across Bed of River. F. Kansrao Rao. G. Former Bed of Kansrao Rao. H. Centre of Works.

arose from the insufficiency of waterway at the heads of the newly excavated cuts at B, and partly from the natural tendency that the slopes of the bed gave the current towards its old direction. By opening out of the heads of these cuts, however, and by a judicious application of bunds and spurs, the river was ultimately conducted over the masonry works, and placed in the new

line upon which it will hereafter run. It has been before explained, that for the maintenance of the torrent in its direct course upon the works, as well as for other purposes in connection with deposits, and the improvement of the low land lying above the inlet, I proposed the application of parallel lines of bund or embankment across the valley, situated at right angles to the torrent itself,

Diagram 82.



E. Bund 1852. F. Old bed of Kansiao. G New bed of Kansiao

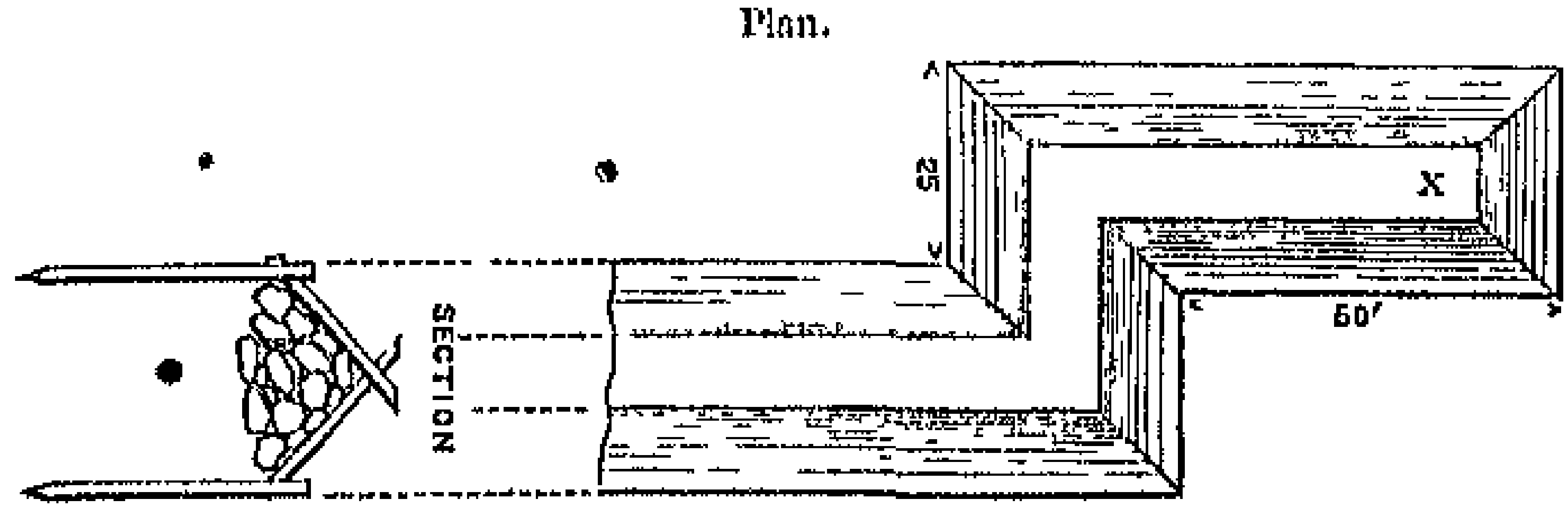
and constructed on the same design as that which had been adopted for similar purposes in the valley of the Puttri. By combining with the temporary bund work necessary for the turning of the course of the river, the

ends of two of the permanent parallel embankments which were part of the original design, the operations appear to have been carried on very successfully; and I cannot do better, when stating the success that attended upon these operations, than give the engineer's own account of his progress.

The above diagram shows the state of the bed of the river in the month of July, 1853, at a period when the most active measures were being undertaken for turning the course of the river over the works. At the points B C D there is high ground situated in the centre of the bed of the river;* at the highest point D, Mr. Login established the end of one of the permanent embankments, similar to that at the Puttri, and in shape and dimensions as follows:—

Diagram 83.

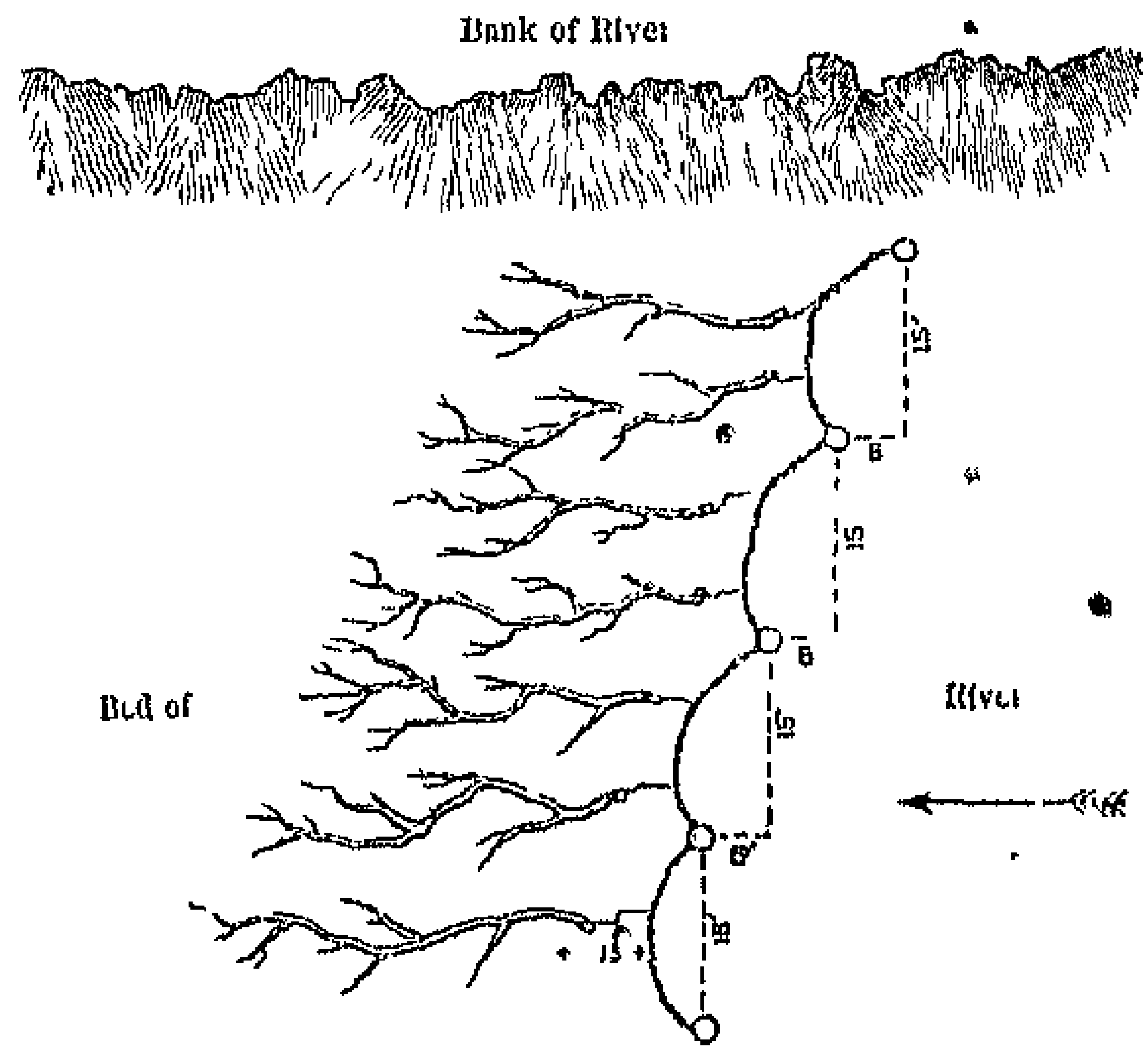
Plan.



The triangular superstructure being made of kurries or rafters, 15 feet in length, of which species of material the piling and necessary protection were also made. The exposed or salient end X, diagram 83, was left as open frame-work for the water to break upon, and the rest was filled with vitrified brick, and masses of overburnt material brought from the brick-fields. By the above arrangement, the current was forced round the head of the spur D, and by meeting an impediment of the same sort at B was urged into the head of the cuts which had been widened out to receive it. Mr. Login, in describing his disappointment in the failure of a spur,

which was thrown out in the early part of the rains of 1853 at the point x, diagram 82, observes that "it struck me that were I to use screw piles, and to tie branches of trees and jungle to their heads (see diagram 84), leaving the material to swing freely at a distance of 25 feet or thereabouts on their down-stream side (by which the piles would be protected from cutting immediately in their neighbourhood), I might get the river to silt up, and form a bank at the spot in question. For this purpose I procured some of the iron chains used in block sinking,

Diagram 84.

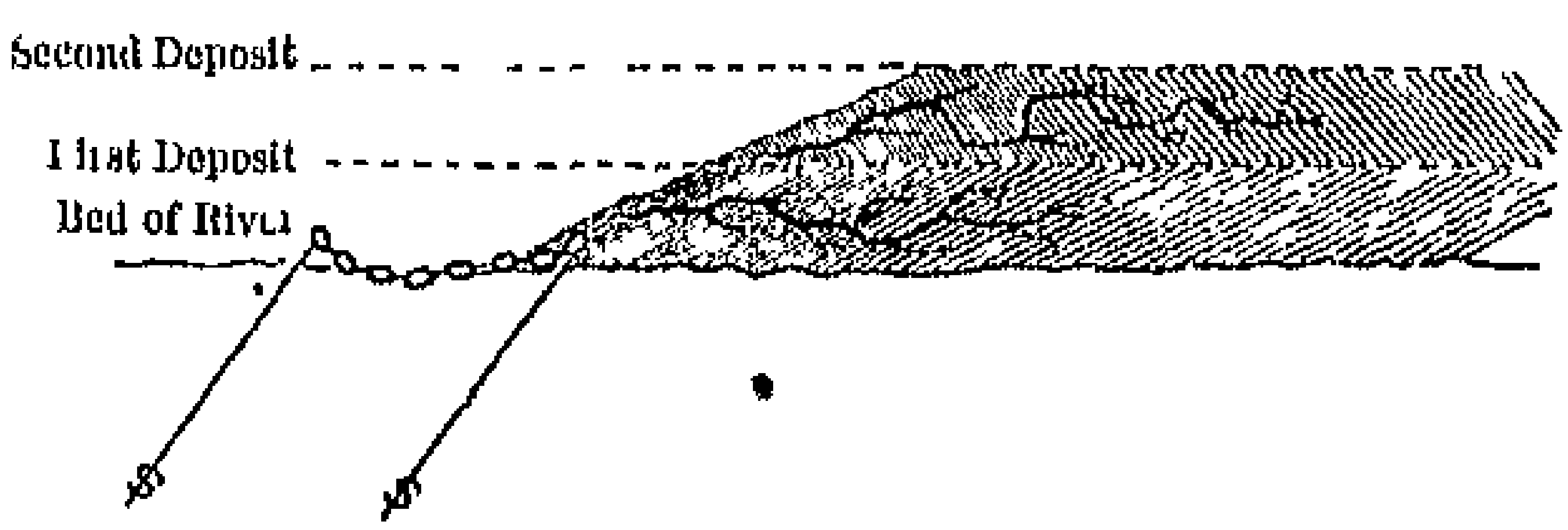


and fastened a quantity of jungle in the way above mentioned, to the pile heads. There were only two piles available, 12 feet in length each, with screws 7 inches in diameter; these were screwed down into the bed of the river, with their upper ring well below the surface; to these the material was chained. A few nights afterwards a small flood came down the river, and to my great astonishment when I visited the spot the morning after-

wards, I found that on each side of the piles, sand equal in length to 300 feet on a breadth of 50, had deposited itself in the form of a bank, nearly concealing from sight the whole of the jungle which had been attached to the pile heads. Seeing this," Mr. Login goes on to say, "I immediately had a number of the screw piles made, and instead of fixing the jungle by long detached chains, I have put the piles in the following position, passing the chain through the rings at their heads, and securing the jungle by rope."

The object of substituting rope for chain was economy in saving the latter, which became so deeply buried in sand that it was irrecoverable. It was imagined that, by additional layers of brushwood after each flood, the sand-bank might be raised to a height above the reach of floods, and by these means form a defensive work of much greater stability than that given by nature herself out of pure sand: this is shown by the following diagram:—

Diagram 85.



"By degrees," Mr. Login says, "I hope to have the bed raised to the height of the natural bank which borders the river, and by extending the use of the screw-piles, to give the river such an inclination to the direct alignement upon the dam works, that there may be no deviation from it hereafter."

The adaptation of the screw-pile (Mitchell's) to the particular purpose to which it had in this case been

applied, is most undoubtedly a great accessory to our river works; it is, in fact, using the pile for mooring purposes, for which it appears to me to be the most appropriate.

II. The works in the Ganges Khadir for the admission of country drainage.

It will be understood from what has been written in previous chapters, that the canal, after it reaches the high land at Roorkee, proceeds on a course keeping as closely as possible to the summit levels of the country. Whether on its main trunk or on its branches, the direction pursues an uniform course between two rivers, by the watershed of which it is entirely guided. The position of the canal channel is on the summit of a ridge, which separates the drainage of its two boundary rivers, above whose beds it is more or less elevated. The beds of the boundary rivers are naturally, as they ought to be artificially, the receptacles for flood drainage, and it has been a leading principle, throughout the whole design, to protect the canal channel as much as possible from the inlet of country water, and to throw the drainage away from the works, rather than to give it any encouragement to approach near them. In all cases where the irregularity of surface drainage, and the tortuous course of the natural watershed, have been intersected by the straight alignement of the canal, measures have either been taken or are to be taken for the effective relief of the flood water by cuts made into its neighbouring river. *In no case ought this rule, in my opinion, to be deviated from; the beds of the natural rivers ought to be considered as the true escapes, and the canal channel ought to be confined to its own especial duties.* My views of the equilibrium that will be maintained in the surface water

by the connection of the main canal and its branches with the subordinate lines of rajbuha, have been fully entered into in the chapter describing the rajbuhas, and their double objects of irrigation and safety valve. It is sufficient to advert here to the fact that during rain the amount of water collected by direct incidence, as well as that pouring into the canal channel through the bridge inlets—which, from their position, it may be noticed are capable of being entirely restricted to the rajbuhas themselves—will add sufficiently to the supply of water passing down the channel, even with the relief afforded by the escapes, to render any superfluous inlet (especially where such is avoidable) unnecessary.

The works that come under this section are distinctly inlets for the reception of flood water from extensive areas of country; they are directly connected with the excavated channel, and they are confined entirely to the tract lying above Roorkee. With the exception of the Lounda Leni Wala and Kunkhul drainage which, however, is more connected with shingle than with sandy-bedded rivers, the water which is admitted through these inlets, is that which falls upon wild and uncultivated surfaces lying at the foot of the siwaliks, and it is free from the sand and silt which characterizes the torrents whose heads are within the mountains.

Of these works there are five, viz.:—

	Width of Water-way.
1st Lounda Leni Wala Inlet . . .	50 feet.
2nd Kunkhul " . . .	30 "
3rd Jowalapoor " . . .	100 "
4th Selimpoor " . . .	150 "
5th Badshahpoor " . . .	50 "

With the exception of the work at Kunkhul, which varies in some respects, the design of these inlets is uniform; it is a combination of ghat or stairs with a passage for the inlet of floods, the flight of steps being

available for access to the canal water for bathing, or for other purposes. The sill or upper step is in all cases retained on a level either equal to or above the maximum high-water mark in the canal, and the flood water on its admission passes over the flight of steps, and is retained within its limits by flank walls.

The local depression of the country at Kunkhul, at the site where the inlet is constructed, rendered it necessary to modify in a slight degree the plan which has been elsewhere adopted; the modification will be understood by referring to Plate XV. Sheet 3, of the Atlas; it consists in a sluice fixed centrically in the flight of steps, so as to admit of the flood water of the country passing into the canal at low levels, when by the closing of the regulator at Myapoor, the channel is comparatively dry. This sluice is fitted with vane planks or sleepers, in the way which is usually practised elsewhere.

These works are built almost entirely with bolders (river stone) collected in the bed of the Ganges and its branches; they are faced with brick; and the use of this material is extended to all parts, where external finish is required, or where the application of lines of brick masonry was considered to give additional stability to the structure. The outer surface is stuccoed, and made of one uniform appearance by a coating of plaster. The whole of these works are designed on a scale of solidity, adapted to the rough work which they will have to undergo; they are strongly protected both on the upper and lower levels by piling and box-work; and no means have been spared to render them as efficient as possible.

It is unnecessary in this place to advert to the causes which led to the construction of these works, as they have been freely entered into in a former chapter: it may be sufficient here to repeat that they are confined entirely to the regions connected with the mountains, and to parts

of the country where the line of the canal, by running at right angles to the natural slope, intersects the drainage. The width of water-way which has been given to each of the inlets, will, it is believed, reduce the action of the current, and render its effects upon the works harmless; and considering them as masonry ghats for giving access to the water, their introduction at detached points will undoubtedly be of great convenience to the people in the neighbouring villages.

The rates or cost of building will be shown by the following table:—

			RS.	A.	P.	
Lounda Leni Wala	Inlet	Masonry	15	2	8	per 100 cubic feet.
Kunkhul	”	”	13	12	8	”
Jowalapoor	”	”	14	3	1	”
Selimpoor	”	”	15	1	0	”
Badshahpoor	”	”	14	8	0	”

The cement which is used in the body of the work, consists of

1 part Stone Lime.
1 part Soorkee.

the stucco or plaster, of

2 parts Stone Lime.
1 part Soorkee.

III. *The works in the Ganges Khadir for the escape of country drainage.*

The works for this purpose are, as it will be understood from the description before given, of an exceedingly limited nature; they are, in fact, confined to one masonry outlet; and an arrangement, to which I have drawn attention, when describing the Selimpoor Inlet, for permitting flood water to pass over the canal channel through

openings left in the embankments above the high-water mark of the canal supply immediately opposite the inlet in question.

In regard to the first, which is situated on the left bank *directly opposite the Kunkhul Inlet, its specific* object is to dispose of the water received from that source, without adding its quota to the sufficiently inconvenient supply which the want of escapes on the line from Myapoor to the Rutmoo River necessarily *collects in the* canal channel. Its waterway is in two bays of 10 feet each, giving a full escape of 20 feet, the sill being on a level with the canal bed, and the soffit of the arches raised to a height of 11·34 feet above it. The openings are regulated by sleeper planks worked in grooves. Independently of its use as an escape for floods, this outlet acts as the head of a line of irrigation that extends down the high land bounding on the right bank of the Ganges; it also provides a supply for mill purposes.

Bolders are used in the foundations and massive parts of the building, whilst brick masonry constitutes the superstructure: its plan, section, &c., are shown in Plate XVI. of the Atlas.

The total quantity of material used, and the rates or cost of the building, are shown in the following table:—

MATERIALS EXPENDED.

Bricks 12″ × 6″ × 2½″	45,075
Bolders	13,361 Maunds
Stone Lime	4,310 Cubic feet
Soorkee	4,220 ,,
Masonry	Rs. 13-12-8 per 100 cubic feet.

The proportions of material in the cement are as follow:—

1 part Stone Lime.
1 part Soorkee.

those of the stucco or plaster are,

2 parts Stone Lime.
1 part Soorkee.

The outlet was begun and completed by Mr. Kay, the assistant engineer on these works, under the supervision of Captain Goodwyn.

The gaps or openings which have been left through the embankments opposite the Selimpoor Inlet are 300 feet in width; they are merely intended to act as safety valves in the event of extraordinarily high floods, to which, from the height of their sill from the bed of the canal channel, they are alone adapted: they are protected by piling and box-work; and although it is possible that their aid may never be brought into requisition, they may in a case of exigency be the means of doing good service. It will be understood, however, that the benefit that arises from these escapes in relieving the main channel from excess of flood water, will, although in a degree comparatively trifling, be negatived by their effect upon the navigable channel, which will be a sufferer in a greater or less degree: the alternative, however, is a convenient one, and as such, may be considered as an useful appendage to the design.

Before closing the subject of escape, I may remark that the navigable channel itself, as well as the mill line, offers in a small degree the means of relieving the main canal under extraordinary pressures of water. It would not be advisable in ordinary cases, to divert either the one or the other from the specific uses for which they were intended; the same species of flood, however, that brought into use the escape afforded by the gap in the Selimpoor embankment, might render the others worthy of consideration. I mention them here as a species of "pis-aller," without the slightest desire or wish of seeing the alternatives practised.

IV. *The super-passages for carrying the Ranipoor and Puttri torrents over the Canal.*

The term "super-passage" has been applied to works on the canals in these provinces, which convey drainage water over the channels, by well-protected and parapeted masonry passages. In contradistinction to aqueducts which carry a perennial supply, and are built for the purposes of a regular flow of water, the super-passage merely acts as a watercourse during floods, and at other periods is subservient to all the purposes of cross communication. On a small scale works of this description are in common use in the Deyra Doon, and on the Western Jumna Canals, in the neighbourhood of the ridge of low mountains, through which the canal channel is carried on its approach to the city of Delhi, there were until lately numerous works of this sort, acting in the double capacity of bridges during the dry season, and passages for the flood water from the mountains during the rains.

The causes which led to the adoption of this species of work on the Ganges Canal, have been fully explained in Chapter 2, Part II. of this history; and the necessity for this adoption, even under the great difficulties * and greater expense which it entailed upon the estimates, has been so fully described, that I shall confine myself in this place to details of design and construction, and to the extent and character of the catchment basins which are dependent upon the super-passages for their thorough drainage.

The works which come under the above denomination are confined to the Khadir, and they have been constructed specifically for the passage of the Ranipoor

* Mr. Login, in suggesting to me the adoption of the plan of passing the canal by super-passage, undertook to overcome these difficulties, and this he has effected in a most masterly manner.

and Puttri torrents. The catchment basins or area confined within the limits of the watershed of these lines of drainage, may be considered as 45 and 80 square miles respectively. That of the Ranipoor torrent averages in width 4½, and has a total length of 10 miles; that of the Puttri is 5 miles in width, with an average length of 16. From the exceedingly intricate lining out of the ravines and valleys in the Sewaliks, it is quite impracticable to determine with any precision the true and accurate line of watershed; for all practical purposes, however, the dimensions above given are sufficiently correct to enable us to estimate with tolerable certainty the value of the enclosed area.

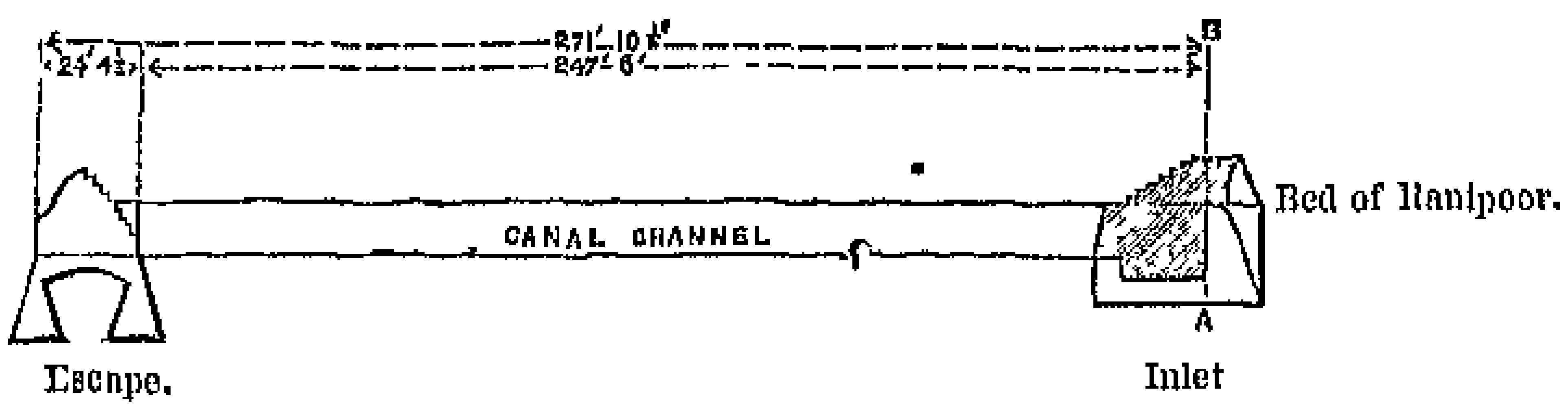
The catchment basins of both the torrents with which we are now dealing, consist of long strips of land, the lower extremities of which terminate on the super-passages. The northern portion of these strips, or that which is farthest distant from the canal, is occupied entirely by mountains, the highest points of which rise to a height of from 800 to 1,000 feet, above the country on which the canal is situated: in both the basins of the Ranipoor and Puttri, at least one-half of their area is thus occupied, the remaining half being on a rapid slope towards the direction of the canal, and having its surface covered with either grass or low forest-trees, to which the cultivated land and villages bear a very small proportion. The hills themselves consist of upheaved alluvium, strata of clay, sand, and bolders, lying at an angle of about 20 degrees: this angle with the exception of that portion of the Sewaliks which is in contact with Hurdwar and the Ganges, dips, I believe, universally to the north-east, showing its scarp to the plains. Immediately at Hurdwar, however, the direction of this dip is reversed, the inclination of the strata being to the south-west. These hills are subject to constant degradation; every rainy

season precipitates masses broken off from cliffs into the beds of the torrents, by the aid of which the detritus is carried forward, and spread over the plains lying at their foot. These plains, which as I have before said, are on a rapid, although gradually decreasing slope in the direction of the canal, consist entirely of the material thus brought down from the mountains, deposited according to its gravity, bolders and shingle forming the slopes of the upper, whilst sand is the prevailing ingredient of the lower regions. It is in this sand that the Ganges Canal has been excavated, and it is in soil more or less of a sandy nature that the works I am now about to describe have been built. Taking the works in their order of precedence, those connected with the Ranipoor torrent will first come under review.

The Ranipoor Superpassage, and Works connected with it.

At the point where this work is constructed, and previously to the project of 1850, a masonry perpendicular drop inlet for the admission of the torrent, and an outlet for its escape, had been built; the former on the right, the latter on the left of the canal channel. The existence

Diagram 86.



of these works, therefore, placed a limit in an economical point of view on the new design, it being desirable to adapt, as far as it was possible, the foundations and superstructure of the old to the new work. The demands for the

passage of the canal water were an open channel of 200 feet in width, a lock channel of 16, and a mill race of 10. It was essential that the flood-water of the Ranipoor torrent should pass over the whole of these channels without any sort of interference. The transverse section of the canal across the old masonry works, is shown in the preceding diagram.

Maintaining the face of the perpendicular of the inlet A B, as the alignement of the right flank of the proposed new building, the space to work upon was equal to 247′ 6″ + 24′ 4½″, or a clear 271′ 10½″. The disposition of the required channels to meet the above width was arranged as follows; commencing from the left of the above diagram:—

	Feet.	in.
Abutment of mill channel	4	2½
Mill channel	10	0
Pier	4	0
Lock channel	19	0
8 Piers, 4′ 4″ each	34	8
8 Waterways of main channel	200	0
Total width	271	10½

It will be observed that the first three items of the above table occupy a space of 18′ 2½″ only, whereas the escape platform was 24′ 4½″; it became necessary, therefore, to cut away 6 feet 2 inches of the front, for the purpose of the lock-chamber: with the exception of this, and the removal of the wings, and a portion of the reservoir of the inlet, the whole of the buildings which were formerly constructed were brought into use as abutments for the new work, into which they were built without any further modification; this will be understood by referring to Plate XIX. of the Atlas, which exhibits the plan of this work in all its details.

I have, in the chapter on Navigation Cuts, explained the method by which the navigable canal and the mill

channel reach the passages respectively appropriated to their uses; and shown how, by means of a revetment, &c., a line of separation has been drawn between them and the body of water in the main channel. It remains, therefore, in completing the description of this work, to note that the waterways, eight in number, for the passage of the main stream of the canal, are equal to that of the falls, or masonry descents, the piers having additional solidity, to correspond with the uses to which the building is to be applied. The water passes over an ogee descent with a drop of 9 feet, and falls into chambers of an equal length with that of the superstructure. This superstructure, which rests on the pier heads, and is formed of floorings, built upon segmental arches, with 60 degrees radius, is, in total width, equal to 210 feet, of which 7 feet on each side are appropriated to parapets, and the remaining 196 to the waterway for the floods. As in the case of the masonry falls, the upper levels of the ogees are fitted with grooves and sleepers for the purpose of closing the chambers, a convenience that is obtained by projecting the pier in the form of a cutwater to the front alignment of the work. The foundations of the upper and lower levels are protected by lines of piling and box-work, the former on a width of 10 feet, the latter on a width of 70 feet; the revetments also on the right and left are similarly protected, and much attention has been given to securing the masonry foundations, which are connected with the main canal channel, from injury. These protective expedients consist of loose bolders, held in position by woodwork; they will require constant watching and repair, and the canal ought never to be laid dry, without an anxious inspection being given, not only to these particular protective works, but to all those which are similarly situated.

The upper floorings, or those of the superpassage itself, are in their thinnest measurement (that is to say, over the crown of the arches) equal to 3 feet. The parapets on the right and left are in width 7 and in height 14 feet; they are continued inland from the body of the work to a distance of 100 feet on each side, expanding outwardly, so as to form wings for keeping the water within bounds, on its ingress to, and egress from, the super-passage.

The plan which has been adopted for giving protection to the masonry work, both floorings and flanks, and of delivering the torrent upon the superpassage channel, is shown in Plate XIX. of the Atlas. The great object has been to bring the torrent upon the work by a gradual process, and to avoid, as much as possible, abrupt contact; to give the current a bearing upon the axis of the passage, and to prevent, as much as possible, any tendency to lateral action. The works at the Puttri exhibit the plans that have been adopted for these purposes on a more extended scale than those which I am now describing, which are, however, equally well adapted for the especial locality. The general design of the spurs and embankments is that which, from long practical experience in Northern Italy, has been considered the best and most efficient; the principle upon which they have been laid out is, as far as local circumstances would permit, similar; and as I have had ocular demonstration of the good effects, not only of the design of embankment, but of the plan which is usually adopted in its disposition, by inspecting the courses of rivers which have been turned under the discipline of works of the above description, I have adopted them without hesitation; and doubtless, with certain modifications dependent on material, and the character of the river which we have to deal with (which, I may observe in passing, are in the early part of their

course similar in every respect to those of Lombardy and Piedmont), they will be as applicable to India as to Italy. At any rate, centuries of experience gained in Europe may very fairly be taken advantage of; and as it is as well to start from the point to which improvement has arrived, instead of persisting in experiments, which, in all probability, have years ago proved unsatisfactory, it is wise to adopt those measures which bear the guarantee of successful experience. I have not been backward, therefore, in adopting as models, those works in Lombardy and Piedmont, which, I was satisfied, both from observations, and from the fact of their practical benefit, would be valuable accessories to our works in Northern India.

The plan which I have put in practice in conducting the torrent and its flood-waters upon the entrance of the superpassage is shown in Plate XXIV. sheet 5 of the Atlas, which representing the works on the Puttri, serves as a pattern for those on the valley of the Ranipoor. It consists of a series of parallel embankments described at right angles to the axis of the superpassage. These embankments, which are made of earth, oppose a salient and well-protected end to the current. An open passage of considerable dimensions, but which decreases in width to that of the masonry channel, is flanked on each side by the salient ends above referred to, the form of which is adapted to restrain the action of the current, to secure back water on the up-stream faces of the embankments, and ultimately deposits of sand along the whole line of the valley. This open, funnel-shaped passage delivers the water upon a strongly built and well-protected series of works more immediately connected with the masonry superpassage, and devised for the purpose of easing off the action of the water on its coming in contact with the masonry.

The series of works above alluded to, consist of flank defences and spurs made of bolders and heavy material strongly tied together by wooden framework, their fronts being covered by aprons of similar material guarded by lines of piles driven to a depth of from 16 to 20 feet. The ingress front of the superpassage itself is covered by an apron of frame box-work, with an upper flooring of rubble masonry; the apron has an inclination of 5 feet, sloping from the level of the floor of the superpassage channel, back in the up-stream direction. The width of this apron is 100 feet; it is carried in a circular sweep, so as to cover the flanks; and the utmost care has been given, by placing these protective works at the lowest possible level, and by guarding them by lines of piles driven as deeply and as closely together as was possible, to place them out of the reach of the whirlpools and regurgitations of water which may be anticipated during floods.

At the point where the water will leave the channel of the superpassage, the works are of a less complicated nature. Here, however, the defences on the flanks, and the apron attached to the flooring, are built of the same material, and much on the same plan, as those on the up-stream face: the object at this point, however, is to get rid of the water, after it has passed through the contracted channel of the superpassages, with the least interference to its onward progress; the side defences, therefore, are merely bunds carried on in prolongation of the masonry wings of the work to a sufficient distance, to deliver the water upon the surface of the country, and the apron is intended to protect the down-stream side of the building from the action of the water in excavating holes on its escape from the floorings.

The connecting link between the wings and the outward defences, is formed by a circular mass of stone and

framework, in which the terminating point of the wing wall is strongly imbedded.

In the above description, I have given a general outline of the works, which have been adopted for both the Puttri and the Ranipoor superpassages for delivering the torrents upon their channels: the extent to which they have been carried in each will be seen by reference to the plans. At the latter, although the defences in immediate connection with the superpassage are precisely of the same order as those at the Puttri, those at a distance are comparatively small; a circumstance arising from local causes, and from the peculiarities of the torrents themselves.

It will be understood, by referring to the Second Chapter of the Second Part, in which I expressed my views as to the effects upon the beds of sandy torrents by the interposition of bars of masonry, that my great object in designing the works which we are now describing, was to depress the flooring of the superpassage to its lowest possible limits, so that its surface should be below the "line of the supposed limit to the action of the torrent."

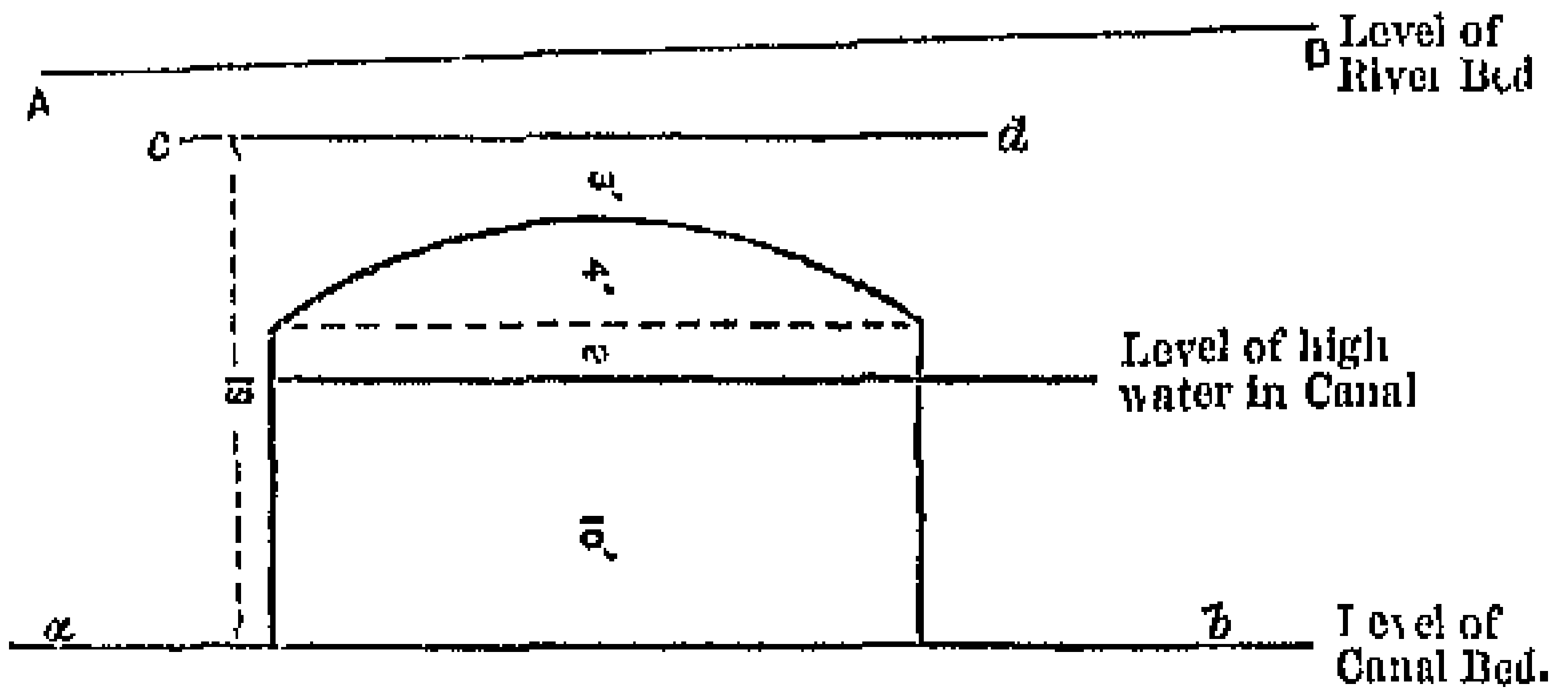
There were two fixed levels to work upon; viz., the surface level of the country, as in the case of the Puttri (or of the torrent, as in that of the Ranipoor), and the true level of the canal bed: between those lines the parts of the design were necessarily restricted. I had to provide for a passage for boats along the navigable line, with a maximum height of water equal to ten feet; and I had to give a sufficient thickness of arch and flooring for the purposes of the passage of the torrent across the canal: for this I considered 3 feet was the minimum that could be fairly given. I had also to provide against the contingency of floods coming down the canal, by giving sufficient waterway for their reception. Whatever, there-

fore, the distance might be between the above two levels, I had a fixed quantity to work upon, viz. :—

10 feet depth of water.
3 feet thickness of masonry for arch and flooring.
6 feet for headway for the passage of boats, and for contingencies of canal floods;

giving a total of 19 feet in depth. The following diagram will still further explain my meaning :—

Diagram 87.



Unless it might be considered that 6 feet was an unnecessary height for headway, the 19 feet above shown was an indispensable and fixed measurement, by which I was limited.

In the case of the Ranipoor superpassage, which was built on the site of the natural torrent, it so happens that the lines A B, and *a b* are separated by a depth of 22·445 feet, so that the flooring *c d* of the superpassage is 3·445 below the true bed of the torrent. I consider this to be a very favourable occurrence, although during the period that we have had the river under our registers, the fluctuations in the height of the bed have been so great, that it is not clear to me what may be the result on the superpassage itself coming into operation. At any rate, the floods will reach the passage in the first instance on a sandy bed, 3·445 feet of which it will have to clear away before it touches the masonry flooring. The Puttri work is not so favourably situated in this

respect; but I shall reserve my remarks on that until hereafter.

I may as well, however, observe that, by the restrictions placed on the height of the superpassage works from the bed of the canal, and more especially from the circumstance of the lock channel being on the left, or on the down-stream end of the superpassage, I have retained the floorings on a horizontal level. It is clear that a slope could only have been given by raising the masonry of the up-stream end in proportion to the declivity required to make it in accordance with the slope of the country. In the case of the Puttri, the rise would have been 1·34 feet, and in that of the Ranipoor 9·07 inches; the former having an effective slope of 25·13 feet per mile, and the latter a slope of 14·11 feet; the length of superpassage channel being in the first case 283, and in the latter 282′ 10½″. Now, as it is perfectly clear that this slope may as well be established by the river itself, and formed of its own material, as built of rigid masonry, I saw no necessity for deserting the horizontal line, but satisfied myself by raising the parapets to a sufficient height to give full scope for any elevation of bed that might be due to the natural slope desired by the river.

The Ranipoor superpassage and masonry works attached are, with the exception of the massive parts of the foundations, floorings, and spandrils, which are built with bolders brought from the bed of the Ganges River, constructed entirely of brick masonry. The whole work was laid out, and its progress was carefully superintended by Mr. Kay, the assistant engineer, under whose care all the buildings in the neighbourhood had been executed.

The bricks, 12″ × 6″ × 2½″, were burnt in the manufactories at the village of Solimpoor, in the same species of kiln as has been used at Roorkee: they are of the best

description procurable from the soil in the neighbourhood.

The quantity of material which was expended on the Ranipoor superpassage is as follows :—

Bricks 12″ × 6″ × 2½″	6,213,753
Ditto 12″ × 6″ × 2″	1,500
Bolders	1,467,814 maunds.
Stone Lime	300,291 cubic feet.
Soorkee	298,898 ditto.

The cement is composed of the following ingredients :—

1 part Stone Lime.
1 „ Soorkee.

with the most abundant use of water.

The rates at which the work was executed are shown in the following table :—

Total content of masonry 1,636,252 cubic feet.

	RS.	A.	P.	
Arch masonry	23	0	3	per 100 cubic feet.
Brick on edge masonry	15	14	4	„
Plain masonry	15	11	0	„
Bolder ditto	10	8	10	„
Plaster	5	8	3	per 100 superficial feet.

Number.	Kinds of earth.	Depth of each Stratum, from the Canal-bed to bottom of Foundations. Ft.	in.	Remarks.
1	Brown sand	3	3	Containing about 10 per cent. of clay.
2	Sandy clay	6	0	A combination of about 70 per cent. of fine sands with 30 of clay.
3	Brown sand	1	6	Containing a slight mixture of sedimentary deposits.
4	Ditto.	1	4	Fine quality.
5	Fine gravel	0	9	Containing about 40 per cent. of sand.
6	Brown sand	1	2	Fine quality.
7	Brown clay	0	6	Containing about 20 per cent. of fine sand.
8	Grey sand	1	9	Good for building purposes.
9	Ditto.	1	9	Fine quality.
10	Brown sand	2	0	Ditto.
	Total depth of foundations.	20	0	

The table given above shows the description of soil that was met with in the excavations for the Ranipoor works. The boring rod showed no signs of water at a depth of 40 feet. At the Moongawalla well, at a distance of 2,650 feet to the westward, spring-water is at a depth of 60 feet from the surface.

I have before described the catchment basin of the Ranipoor torrent, or that part of it at least which lies on the up-stream side of the canal, as equal in area to 45 square miles, one-half of which consists of mountain, and the other half of open forest country; the latter on a very rapid slope towards the canal. A map of the country lying between the foot of the hills and the canal, with its surface marked by figures, denoting the relative levels with reference to the flooring of the regulating bridge at Myapoor (the zero from which all the canal levels are counted), will be found at Plate III. of the Atlas.

The quantity of rain-water that would fall upon a surface equal to 45 square miles, allowing 12 inches in perpendicular depth during 24 hours, would be equal to 14,520 cubic feet per second, an amount that may be considered a maximum on an extended area. The value of the channel of the superpassage to meet the discharge may be estimated by the following table:—

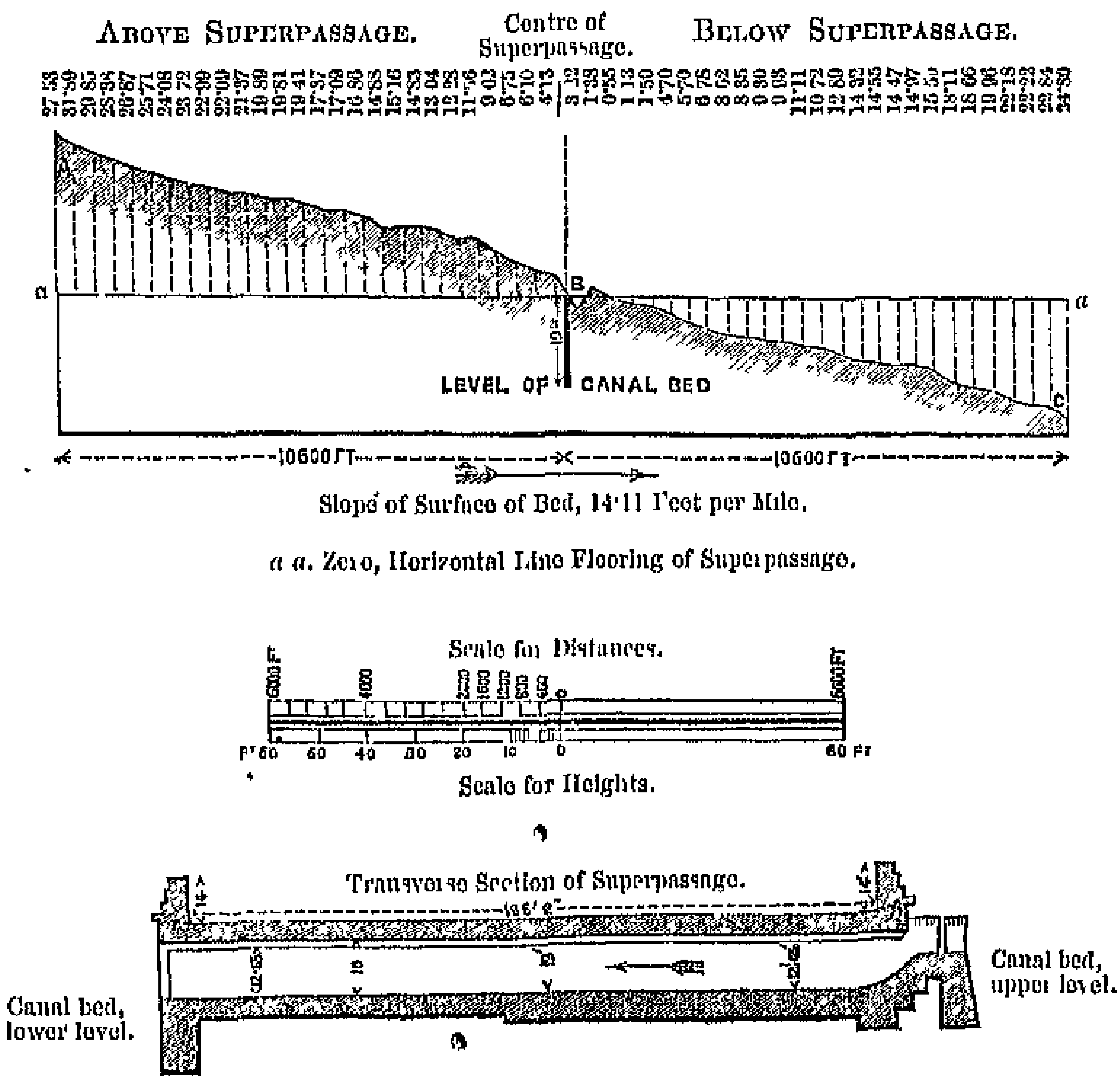
D.	R.	Velocity.			Area.	Discharge per Second.
		V.	u.	U.		
1	11·879	5·127	7·546	2·708	196·167	1,005·718
2	23·520	7·279	10·188	4·370	392·331	2,855·799
3	34·932	8·907	12·137	5·677	588·501	5,241·778
4	46·119	10·258	13·730	6·786	784·668	8,049·128
5	57·098	11·431	15·104	7·758	980·835	11,211·925
6	67·849	12·475	16·315	8·635	1,177·002	14,683·100
7	78·404	13·423	17·410	9·436	1,373·169	18,432·047
8	88·760	14·292	18·410	10·174	1,569·336	22,429·186
9	98·923	15·097	19·331	10·853	1,765·503	26,653·789
10	108·897	15·869	20·212	11·526	1,961·670	31,129·741

Where the first column gives the depth of the water passing through the channel, with the discharge of cubic feet per second, and its attendant velocities in parallel columns.

Agreeably to the above table, a depth of water on the channel equal to 6 feet, would in one second carry off the water that would fall in that space of time.

Diagram 88.

(Levels of the Bed of the Ranipoor Rao, 1853.)



By reference to the above section, which shows the true slope of the torrent on its approach and departure from the floorings of the superpassage, it will be seen that the former, A B, is on an average of 15·88, and the latter, B C, of 12·35 feet per mile.

Giving a mean on the whole distance of 14·11 feet per mile. It is upon the mean slope that the table of discharges above given is calculated; and it is upon the diminution of the slope from B to C, or from the flooring of the superpassage downwards, that I depend for the establishment of deposits in the region of B, or both on, and in the neighbourhood of, the floorings of the superpassage.

The Ranipoor works were built under the superintendence of Captain Goodwyn, by Mr. Kay, assistant engineer, whose success in managing the torrent, and in counteracting its effects upon the defences, during the period that the building was going on, was most deservedly the theme of universal admiration.

The Puttri Superpassage and the Works connected with it.

This work is similar in design to that at Ranipoor, with the exception of the absence of the mill channel. There are, however, nine bays of equal dimensions, each of 25 feet in width; that which constitutes the lock-chamber being 25 instead of 19 feet, as at the Ranipoor works; and the width of superpassage being 296 feet instead of 196′ 2″.

The country which is drained by the Puttri River, or that which, lying on the right of the canal, constitutes the catchment basin for the drainage of which provision has to be made, is bounded on the north by the Sewalik watershed; on the south by the canal; on the east by the watershed of the Ranipoor basin; and on the west by that of the Rutmoo River. A careful inspection of Mr. Dodsworth's map (Plate III. of the Atlas) will show very distinctly the connection, or partial connection rather, that exists between these three lines of drainage. The watersheds of each are accurately defined, but both

in the case of the Ranipoor, as lying on the boundary of the Puttri, and in that of the Puttri, as resting upon the east of the Rutmoo basin, the natural separations of the drainage are very indistinct. As I have shown in the early part of this history, when describing the marked topographical features of the country, there is a direct slope from east to west, parallel to the line upon which the course of the canal is carried: this slope affects the different basins more or less, and is very observable in the upper parts of the Puttri, where from the levels of the surface, it would appear that the basins of the Puttri and Rutmoo are actually connected, and that as far as these levels are concerned, the whole of the water that comes from the Sewaliks, and which now passes down the Puttri, might with ease be thrown into the Rutmoo. The facility offered by this latitudinal slope for relieving one river at the expense of another, has been before alluded to; and it is by no means impossible that it may be convenient hereafter to take advantage of these facilities in relieving the Puttri superpassage, by turning the hill supply towards the Rutmoo dam. This change of direction would require careful management, so as to prevent the torrent from coming in contact with the canal on that part of its channel lying on the west of the Gurh and Synibas ridge, or of its gaining admission into the channel by the Badshahpoor Inlet; but at the same time it is feasible, and may be considered as a resource in the event of the Puttri superpassage being overloaded.

The catchment basin of the Puttri, or the tract confined within the boundaries before mentioned, has in the design for the works which have been constructed, been divided into two distinct areas; one of which is connected with the Selimpoor line of nulla, and with a jungle tract of 10 square miles in superficial extent, which may be considered as subordinate to, and lying to the

east of the true drainage of the Puttri; the other the Puttri itself. The first, as being unconnected with the hills, is remarkable for throwing off pure water unmixed with sediment; the latter for its disgorgements of sand and silt, marked by the true characteristics of Sewalik drainage.

The subordinate area which may be termed the Selimpoor basin, the extent of which is equal to 10 square miles, but which during very high floods is supposed to be liable to an accession of water from the neighbouring torrents, is provided with an inlet of 150 feet in width, situated on the right bank of the canal; the flood water, therefore, from this source will pass down the canal channel, and obtain an escape at the Rutmoo dam. It has been provided also, that the floods in extraordinary cases should have the means of escape over the country situated to the south of, and opposite the inlet, by openings for its passage through the left embankments of the main canal channel. The actual area of the catchment basin, for the drainage of which the superpassage has been constructed, is therefore equal to 80 square miles, minus that occupied by the Selimpoor basin: of these remaining 70 square miles, 40 may be considered as mountain, and 30 jungle and grass land, the latter being on a rapid slope directed upon the works. It is with these 70 square miles that the superpassage which I am about to describe is specifically connected.

The Puttri torrent so far differs from the Ranipoor, that whereas the latter is at the point of intersection with the canal, a well-defined and marked channel, the former is merely shown by extensive beds of sand, superficially distributed over the surface of the country. There is, however, the same remarkable difference of slope between the channels on the up-stream and down-stream sides of the superpassage; and this difference is greater in both

cases at the Puttri works, which with its position relatively to the canal bed, places it under even more serious difficulties than those met with at the Ranipoor torrent. Its distance from the foot of the hills is 5 miles, that of the Ranipoor work is 2¾ miles.

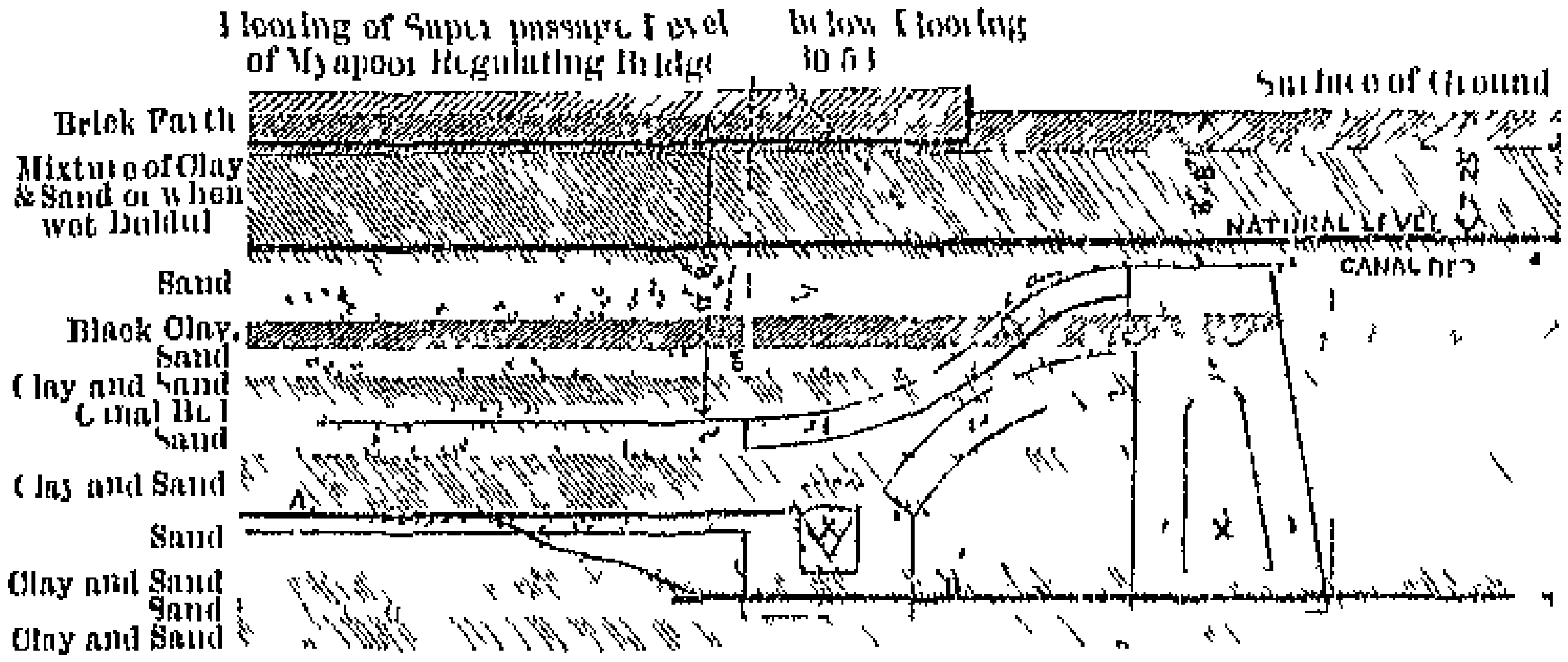
I have in the prefatory remarks on these super-passages, described the nature of the embankments and spurs which have been constructed in the valley of the Puttri, for the purpose of bringing the floods to bear upon the masonry works. I have also described the protective measures that have been taken at the point where they come in contact, for relieving the super-passage from the action of the current. It is unnecessary, therefore, to enter further on this subject, as the detail shown in Plate XXIV. of the Atlas will make this part of the project sufficiently intelligible. It will be seen, however, by this plate, that the actual position of the super-passage is to the west of the natural line that the torrent has during late years taken; this westerly site was determined on for two reasons: 1st, that the work might be executed without hindrance during the period of floods; 2ndly, that the deep excavation which had to be made from the Rutmoo back to the site of the Puttri works, might be reduced in length as much as was possible. The value in point of economy of the latter reason will be understood by referring to the following diagram, which shows the nature of the soil through which the excavation for the Puttri super-passage was carried, and the height at which spring-water was found.

Now it will be seen from the following diagram that the actual depth of digging from the surface of the country to the canal bed on the higher levels was 8·8, that to gain the lower levels was 17·8 feet. To reach the level on which the curtain and ogee foundation rested, the depth to be dug was 28·8 feet; that of the floorings on the

greater part of their extent was 23·8, on the lesser part, 22·8; the tail foundations had to be sunk to a depth of 37·8 feet from the surface of the country, below which there was spring-water at a depth of 7·25 feet.

Diagram 89

Section showing the different Strata of Earth at the Overfall of the Puttri Super passage



A Depth to which springs were reduced by drainage cuts
B Depth to which springs are reduced on this day, May 6, 1851, by the use of dalls on site of overfall

Plate XXIV. Sheet 6, of the Atlas, gives an outline of the floods of 1850, and their effects upon the Puttri works, which, previously to the rainy season of that year, had been commenced by the establishment of embankments for the protection of the works, and by the formation of a channel 300 feet in width, to which it was intended to limit the torrent. The different works that were constructed at this period are shown in the plan above alluded to.

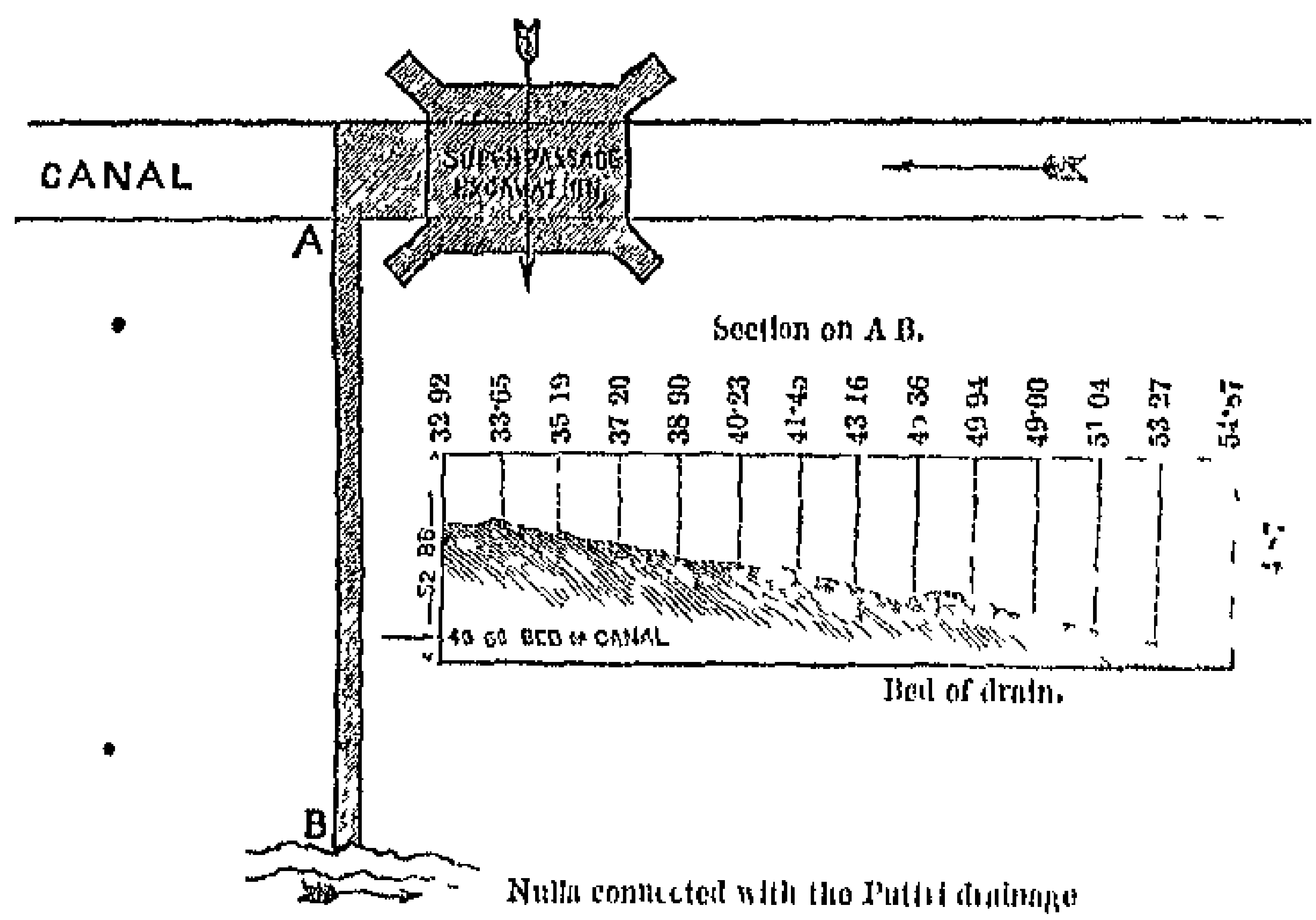
The effects during this season appear in their action to have been quite independent of any of our proceedings; the current in an early part of its course, and high up on the bed of the river, spread over the country, taking a direction to the east, and to that point of the canal where the Solimpoor Inlet is now built; a considerable portion of the current, in fact, passed into that portion of land which has been designated the Solimpoor Basin; here it crossed the canal banks which

had been partly formed, and filling in a good deal of the excavated channel, swept over the country, leaving breaches through the banks, as are shown in the plan. The main body of water, however, continued in the direction of the 300 feet opening which had been left for its reception, through which, during the greater part of the season, it passed, without injuring the flank defences, excepting on one occasion, where it broke into the super-passage without doing any material damage. On the 29th September, 1850, however, in defiance of the defensive works, a flood which occurred during the night-time, carried away the left flank of the opening entirely, and widened the channel to an extent of 147 feet. The general effect of the passage of the current through the opening during this period, was undoubtedly to *deepen* the channel where it was most contracted, and the extent to which this took place is shown in fig. 2 of the plate above referred to. During the rainy seasons of 1851, 1852, and 1853, the torrent has still, in a greater or less degree, passed off in the divided stream, it having been thought advisable for the security of the super-passage during its construction, to leave the breaches open, and by these means to give relief to the passage of the water at points distinct from the masonry works. In this manner the floods for three years have gone by without giving any trouble. The bed of the opening has during this period, although passing off large volumes of water, experienced a variety of changes, and at the time that I am now writing (1853–54) is above its original level, being covered with sand deposits, as it was previously to the floods of 1850.

The great (it may be said extraordinary) difficulties that the engineer in charge had to contend against in laying the masonry of this work, must, under the above explained circumstances, be evident. Mr. Login, how-

ever, succeeded in reducing the spring-water level to a depth of 18·25 feet from the surface of the country, and in laying in the whole of the building, foundations included, with little or no impediments from water. The tail foundations, which consisted of blocks of masonry, were undersunk to a depth of 20 feet, and those portions of the curtain and ogee walls below the reduced spring level, were laid in by the use of dalls or scoops, by which the water was entirely removed from the excavations.

Diagram 90.



The situation of the canal (crossing at right angles a country lying on a rapid slope) was peculiarly favourable to the operations for drainage, and this was taken advantage of in the most economical way by making a cut from the canal bed in the direction of the slope; and as the spring-water passed away, gradually deepening both the excavations for the works and for the drainage, until the water was reduced to a minimum. The plan adopted is shown in the above diagram, accompanied by a profile of the country on which the drainage cut A B was excavated.

The design was simple, and its success complete. I am not aware that during the whole of the building operations any further difficulty existed than in the maintenance of the drainage cut as a free and open line. This, as might be expected, was on its lower levels subject to the falling in of earth from its side, and to deposits of mud and sand from the action of springs and currents. There was a constant necessity for working parties being employed upon it, but the free passage of the spring-water which it secured, rendered the progress of building comparatively easy.

The soil upon which the masonry rests is far from being a satisfactory one; the circumstance alone of its being saturated with springs, independently of the soil itself, in which the springs act, being composed of a mixture of sand and clay, is an evil of great magnitude. I have trusted, however, to the massiveness of proportions of the foundations, and to the extensive surface which they cover, equal in area to $331\frac{1}{2} \times 285$ or $94,477\frac{1}{2}$ square feet, as a protection against any serious disarrangement of the superstructure by after-settlement. The result, however, has not proved so satisfactory as could have been wished, the line of blocks at the tail has led to a slight settlement, arising, I imagine, from the crater-like form which is given to the soil in the progress of undersinking, and consequently (in all probability) to an inclination that these solid masses have to move after the superincumbent weight was placed upon them. The flooring of the left chamber, or of that devoted to lock purposes, which from motives of economy was reduced in thickness to $2\frac{1}{2}$ feet, has also slightly settled; these defects, however, will not, I imagine, act prejudicially, nor will the settlement proceed further than it has already done.

The building is constructed entirely of brick ($12'' \times 6'' \times 2\frac{1}{2}''$ in cubic measurement, burned in the Solimpoor

manufactories) and boulders, the latter being used in all the massive parts of the foundation; the former in the outer surface (18 inches thick) of the ogees and floorings, and in the super-structure. The centerings for the arches were formed of earth well watered on the native plan, which has, as a general rule, been adopted throughout these works. With certain disadvantages, which are noted in the chapter on Bridges, this species of centering has the great recommendation of cheapness, added to a facility of adaptation to the purpose, which no other species of centering offers. The boulders, of which the foundations are built, and which are so extensively used in the protective works appended to the super-passage, were collected at the mouths of the passes into the Sewaliks, and from the bed of the Ganges River, from whence they were carted to the works at a cost varying from 4 rs. to 4 rs. 8 as. for 100 maunds, from a distance of from 5 to 7 miles, or from 8*s*. to 9*s*. for 3½ tons.

The following quantity of material was expended:—

Bricks, 12″ × 6″ × 2½″	9,411,011	
,, English machine	366,144	
Boulders	1,401,262	maunds.
Jhama	23,248	cubic feet.
Stone lime	285,757	,, ,,
Soorkee	408,915	,, ,,
Sand	80,479	,, ,,

And the proportions used in the cement were as follow:—

Boulder masonry	1 Stone lime. 1 Soorkee. 1 Well-washed sand.
Brick masonry	1 Stone lime. 2 Soorkee.

PROTECTIVE WORKS.	PLASTER.
10 Stone lime.	3 Stone lime.
10 Soorkee.	2 Soorkee.
10 Sand.	
5 Lime siftings.	
5 Small broken brick.	

The whole being finished off with a mixture of 7 parts of stone lime to 1 of soorkee.

The rates of work performed will be shown in the following table:—

Total cubic content of masonry, 2,248,591 cubic feet.

	RS.	A.	P.	
Arch masonry . . .	23	15	1	per 100 cubic feet.
Brick on edge masonry .	19	1	2	" "
Plain masonry . . .	16	13	8	" "
Plaster	2	3	5	per 100 s. feet.

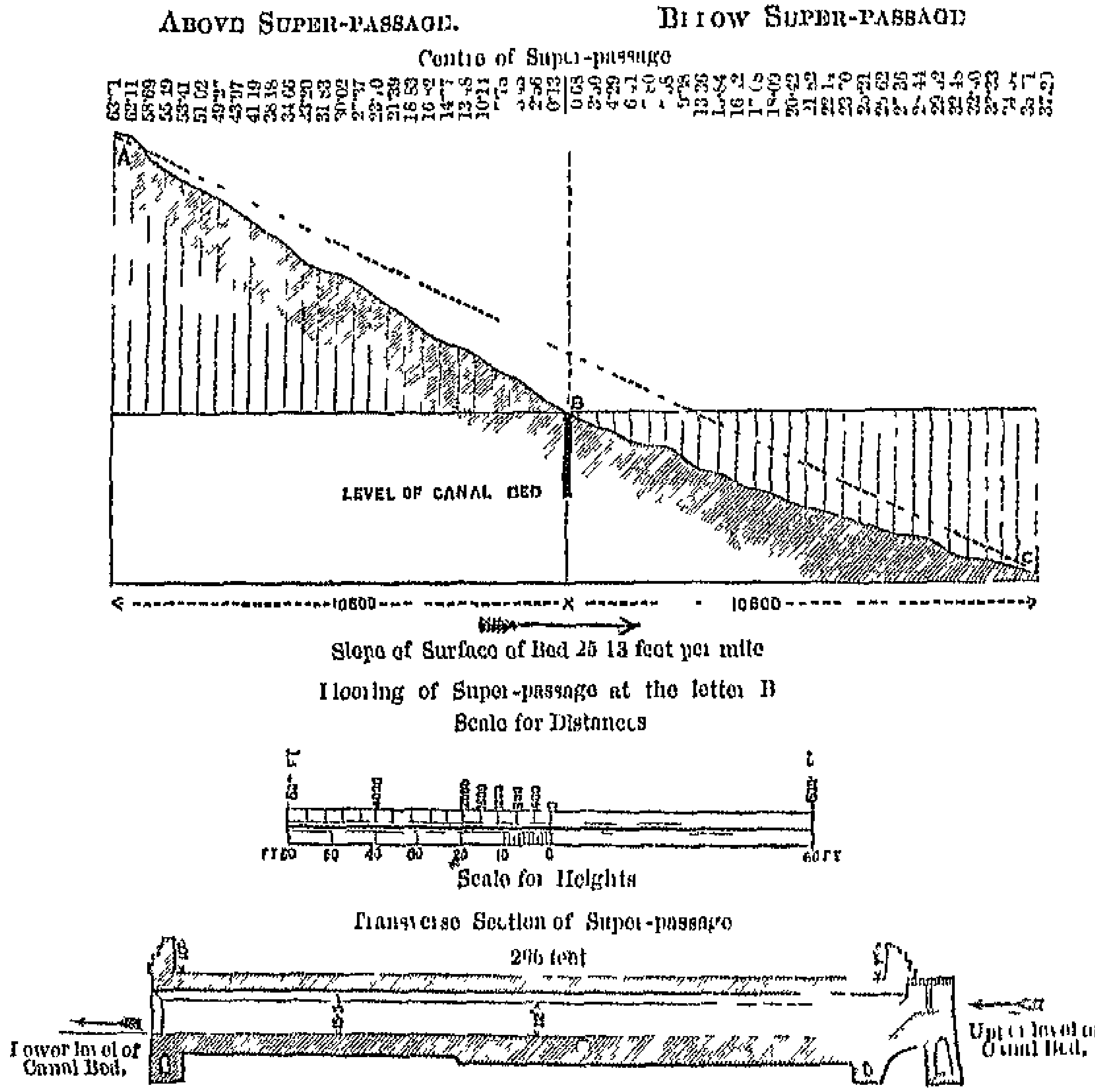
The calculations for the discharge through the channel of the super-passage have been made on the plan before described for that of the Ranipoor work; the effective slope being estimated on the mean of four miles, two of which are on the up-stream, and two on the down-stream side of the masonry channel: the sections which accompany the present description have been taken since the works have been completed; they show, therefore, the true declivity of country in connection with the works, and fully exhibit the diminution of slope on the down-stream side, as tending to deposits in the region of the masonry work. Taking the mean of the slope on four miles as 25·13′ per mile, the following table will show the value of the Puttri passage in its capabilities of discharge to a depth of 10 feet of water on its floorings:—

D.	R.	Velocity.			Area.	Discharge per Second.
		V.	v.	U.		
1	11·919	7·131	10·009	4·253	296	2,110·8
2	23·680	10·143	13·597	6·689	592	6,004·7
3	35·285	12·432	16·266	8·598	888	11,039·7
4	46·737	14·340	18·479	10·201	1,184	16,978·0
5	58·039	16·006	20·368	11·644	1,480	23,688·0
6	69·195	17·497	22·062	12·932	1,776	31,075·0
7	80·206	18·855	23·597	14·113	2,072	39,068·0
8	91·077	20·107	25·006	15·208	2,368	47,613·0
9	101·809	21·271	26·311	16·231	2,664	56,666·0
10	112·405	22·361	27·531	17·191	2,960	66,189·0

The above table is calculated from the mean slope

obtained from the following section, which shows that the slope of approach A B is equal to 31·73 feet per mile, and that of departure B C, equal to 18·53 feet per mile.

Diagram 91.



LEVEL OF THE BED OF THE PUTRI NUDDI, 1853.

The supposititious dotted line A C which represents the mean slope upon which the calculations of discharge are founded, exhibits also the theoretical boundary to the extent of deposits on B.

The establishment for the supervision of the super-passages will be connected with that of the line of navigation which runs parallel to them; they will be under the immediate charge of an overseer, whose

duties will extend from the Jowalapoor Bridge on the up-stream side of which the navigable line commences, to the down-stream side of the Puttri super-passage, at which point the navigable line terminates. To each of the four locks, two of which are connected with the super-passage buildings, a gang consisting of one mate and ten beldars will be attached; giving to the whole line a party of four mates and forty beldars. Independently of the lock duties and the management of the navigable channel, the overseer will be expected to maintain the embankments and roads within the limits above specified in a perfect state of order as regards the annual repairs and jungle clearances.

V. *The Inlets which form a component part of the Bridge and of the Rajbuha Channels.*

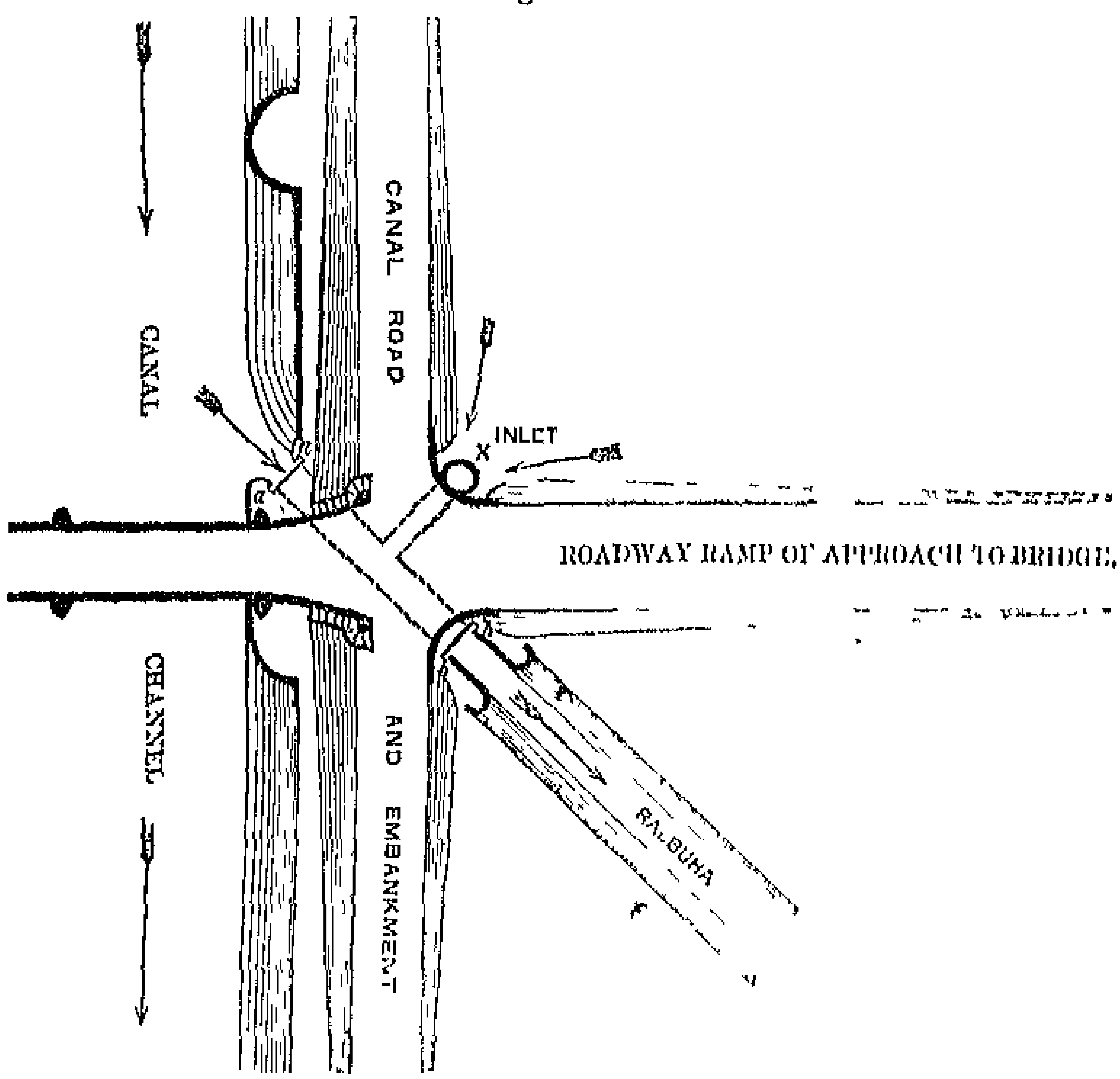
I have before noted that, after the canal reaches the high land of the Doab, the principle upon which the works have been designed, precludes as much as possible the occurrence of inlet water; all flood water and country drainage are thrown into the beds of rivers, which are the natural escapes for them; and the works for inlet on the canal channel are confined to the relief of the land lying in the immediate neighbourhood of the works. The inlets, in fact, from Roorkee downwards, consist entirely of masonry channels, either attached to and forming component parts of bridges, or built in connection with the navigable channels, that pass round the falls. All the inlets of this description have been so arranged, that the admission of water into the canal channel should be through an opening, either in a line of revetment or wall of some description or other, so that the effects of a current upon the isolated head of a detached building, might neither disfigure the channel in the vicinity of the

inlet; nor lead to deviation in current which projecting parts of masonry are very apt to be the cause of.

With this view, the inlets, which consist of a channel 3 feet in width, terminating in a circular well or reservoir, which acts as the receiver, are built universally, either in connection with bridges, attached to the waste channel of locks, or with their channel passing through a ghat, the steps of which act as a curtain of defence on the canal side.

The bridge inlets are placed in the position shown at × in the following diagram :—

Diagram 92.



The roadways of bridges throughout the whole of the works are horizontal, and the ramps of approach are constructed on a slope of 2 feet in a hundred, excepting

on the lines where the Grand Trunk Road crosses the canal, in which case the slope is reduced to 1 in 100. The elevation of the bridge roadways, therefore, above the surface of the country, varies with the depth of canal excavation; taking it in extremes, the maximum is 18 feet, and the minimum is 6; the average height may be estimated at 8 feet: it is clear, therefore, that as the slope of the country and that of the canal are in one direction, the intervention of the ramps of the bridges must in their immediate locality interfere largely with the drainage. To remedy this interference, the above species of inlet was devised, the top of the well at × being in all cases on a level with the high-water mark of the canal. Wherever (as was the case at Kunkhul as described in the former section) the surface of the external country in the neighbourhood of × is low, a sluice with shutters is arranged in the side of the well, so that during periods of low water in the canal channel, the inlet may be turned to account.

It will be observed that the inlet channel opens into that of the rajbuha, by which it might naturally escape, without interfering at all with the supply in the canal. As this is a point which requires regulating, I have, in addition to the necessary sluice arrangements at the head of the rajbuha (vide *a a* in the diagram), placed corresponding ones on the down-stream side of the channel at *b b*, so that, if necessary, means may be offered for preventing the inlet water from passing down the rajbuha, by closing the sluices at *b b*, and leaving those at the head open. This double plan of sluices enables the supervising establishment to regulate the disposal of the water, according to the exigencies of the moment. There will be times when the relief of the rajbuha channels will be of the greatest benefit; at other times it might be inconvenient from the rajbuha channel being out of order,

to allow water to pass down it; at any rate, the mere fact of holding the power of doing as we please with the water is an advantage which cannot be too highly estimated.

Independently of the mere drainage-water, which is intercepted by the bridge ramp, the boundary ditches of the canal must necessarily tend to bring down a supply from the canal bank and land lying in its neighbourhood: the inlets will be of great service in disposing of this water; and as the canal chokies in all cases are built not far from the inlet-head, and in the angle formed by canal embankment and the bridge ramps on its up-stream side, the ground in their vicinity can always be kept high and dry, and entirely free from standing water. The bridge inlets are, in fact, admirable auxiliaries to the system of external drainage, and will, it is to be hoped, relieve the works from all superfluous water.

Drains similar in design to those above-mentioned, are attached to the works on the Solani Aqueduct in the neighbourhood of Roorkee. The workshop yard, and the esplanade in front of the main buildings, have their drainage disposed of by wells connected with the canal by underground channels. Similar inlets are also attached to the cattle ghats, for the drainage of the country in their vicinity.

The esplanades on the right and left of the canal on its approach to the Ganges at Cawnpoor, have inlets designed on the same plan, for their drainage, as well as for that of the town and bazaars which run parallel to them.

The space enclosed by the navigable cuts, which are designed for the passage of craft at the points on the canal where the great descents or falls occur, is drained by inlets of a similar description to those above-mentioned. These inlets are connected with the waste channels of the locks, and the rain-water that falls upon the

surface included between the line of main canal and that of the cut, is brought to bear upon the mouth of the drains by excavated channels. In the event, however, of the above islands not being sufficiently drained by the lock inlets, the centrical situation of which may in some cases be inconvenient, I see no harm in supplemental drains being constructed at points near the junction of the navigable with the main line: these inlet drains would open into the navigable, or lock channel, in which the body of water is comparatively small, and the consequent action of current moderate; their canal fronts might with great propriety be protected by a line of ghat, the advantage of which, in affording an approach to the water, will always be highly appreciated by the native community. As these well-heads would be connected with the natural surface of the country, generally speaking, on its lowest levels, the effect upon the drainage of the island would, undoubtedly, be beneficial. It will be evident, however, that in addition to the value derived from these well-headed drains as inlets for flood-water, they act during dry weather in affording access to the canal supply for various purposes. The mango-graft plantations are invariably situated near the bridge inlets; and the nurseries of forest-trees, and plantations for brushwood, are in all cases spread over the island formed by the main and navigable canals: to the whole of these plantations they would afford the means of irrigation. The multiplication of this species of inlet in connection with the islands, may possibly be economically convenient as affording the means of irrigation to tracts of plantations scattered over extended surfaces. I am by no means satisfied that this might not have been done with advantage in the first instance, although motives of economy prevented me from putting it in practice.

The only species of inlet remaining to be described,

is that in connection with the bridge-roadways, which in their passage over the canal are flat; the drainage here is effected by vertical holes perforated through the crowns of the arches, whereby the rain-water passes off into the canal channel. This method of disposing of roadway drainage is preferable in every respect to that of carrying off the water by side-channels, which are invariably troublesome, and in many cases inconvenient.

CHURCH AT ROORKEE.
(Designed and built by Lieutenant George Price, 1st Fusiliers.)

Chapter II.

REGULATING WORKS FOR THE SUPPLY OF WATER AND SLOPE OF CHANNEL.

This chapter may be divided into four sections :—

I. Regulating bridges.
II. Heads of branches.
III. Escapes.
IV. Falls.

Under the preceding, I include all works of the above description which are distinctly connected with the regulation of the canal supply for the purposes of irrigation. It is impossible to draw a precise line between the first three items of the present, and those described in the last chapter; they do, in fact, during floods, act either in maintaining a convenient distribution of the superfluous water, or, as in the case of the escapes, in getting rid of it altogether: so under the head of Dams, which naturally fall under the denomination of drainage, works of this description afford the means of regulating the supply for irrigation during the dry months, as well as of relieving the channel from the torrents with which it comes in contact during the rains; the regulating bridges, moreover, are as distinctly a component part of the dams, as the sluices in the dams themselves, and are as necessary a part of their machinery during floods, as the sluices themselves are. It will, however, be understood that the

present chapter is specifically devoted to the works for the irrigation supply, whilst that on Drainage is confined to those for the relief of the canal channel from what we may call torrent water.

I. Regulating Bridges.

With the exception of the Dubowli and Moosanuggur regulators, which are connected with the terminal works of the Cawnpoor and Etawah lines, under which head they are described, this section is limited to—

A. Myapoor regulator;

B. Dhunowri do.;

the details of which have been fully entered into in the last chapter. For drainage purposes, these works act as dams across the canal channel for preventing either the floods of the Ganges, or those of the Rutmoo River, from gaining admission into it; they confine the torrents to their own courses, and for this purpose they are of the highest importance. For irrigation purposes, the regulators at the above points admit during the dry season of the supply being adjusted to the periodical demands for irrigation; and in the event of accident to the masonry works, or of a necessity for repair to the channel, they provide the means of turning the water off altogether, and of laying the canal perfectly dry. To ensure the satisfactory and ready accomplishment of all the details dependent on the working of the machinery for closing and opening the regulators, permanent working parties, consisting of four mates and forty beldars, are attached to each of the bridges. These parties will be under the immediate control of an overseer resident on the spot, who will subject them to discipline in periodical drill by working the apparatus, both of the dam and regulators; monthly, or oftener if necessary, an inspection of this

part of their duty ought to take place under the eye of the Executive Engineer of the division; and the director of the works would on his periodical visits consider a parade of the whole party with the evolutions attendant upon the opening out and closing of the dam and regulators, a ceremony with which he ought to be received, on his reaching the works.

It is, I believe, impossible to place too much weight on the necessity for maintaining these corps of working parties in the most efficient state of discipline, the safety of the works will depend upon it, and the whole country may have to deplore the negligence or incapacity of the working establishments of the regulators. I should be inclined to select one of the best and steadiest overseers for the charge of each of these works, and endeavour to make it a post of honour, as I would of emolument, by giving each overseer an addition to his monthly pay of 25 rupees, providing accommodation for him also at the public expense: the duties of these overseers would be to look to the efficiency (including physical strength) of the party under his orders, to see to its being properly drilled, and to its discipline being maintained under orders provided by the Executive Engineer of the division.

At Myapoor, the overseers' duties would extend from the Ganges (to the bunds and embankments on which his attention would be given) to the up-stream side of the Jowalapoor bridge; and it is supposed that during the dry periods of the year, when the dams and regulators were little used, the beldars who are divided into four gangs, consisting of one mate and ten men each, would be sufficient to maintain the whole of the roads, and the whole of the embankments in a state of the highest order and tidiness.

At Dhunowri, the overseers' duties wou

from the Puttri super-passage on its down-stream side to the up-stream termination of the Solani aqueduct works, the total distance being 6¼ miles. The remark that I have made with regard to the duties of the beldars during the dry season, would be equally applicable here; and I imagine that the whole of the roads, embankments, and space between the canal boundaries, including the esplanades connected with the works at Dhunowri, may be kept in the most perfect state of order by the beldar parties. One of the chief duties of the overseer at this post, will be to see to the efficient working of the under channels at the regulator, to take care that they are maintained in a free and unimpeded state, and that no inundation is allowed to collect above the works. Rules on this subject, together with regulations for the discipline of the beldars, might, with great advantage, be printed, and hung up in the public buildings. I would recommend that these rules and regulations be printed in Hindi and Oordoo as well as in English.

II. *Heads of Branches.*

These works are in form identical with the regulators described in the last section; their purposes, however, are merely those of regulating the supply of water from the main trunk to the branches. They are useful in giving us the power of stopping supply altogether, when laying the branch dry for repairs. They are equally useful when the supply does not exceed the capacity of the branch in laying the main trunk dry, and of converting the branch into an escape. Collectively, they may relieve the main trunk, and with the aid of the escapes, do all that is required without the aid of the regulators described in the first section. Practice and the electric telegraph will render these works of the

highest value and importance to the regulation of supply. They come under the following heads:—

A. Head of the Futtigurh Branch.
B. Do. Bolundshuhur do.
C. Do. Koel do.
D. Works at the Nanoon Fork connected with the terminal lines to the Ganges and the Jumna.

A. The Futtigurh branch leaves the main trunk on the left at the 50th mile of its course at an angle of 60 degrees; its supply is calculated at 1,240 cubic feet per second, and the main trunk, after having disposed of this supply, passes onwards in a volume equal to 5,180 cubic feet per second. The slopes of the channels of both the branch and main trunk are equal, viz., 15 inches per mile, and the soil through which they pass consists of a combination of clay and sand, in which the latter predominates.

I have in diagram 19, in the second part of this paper, given an outline of the works attached to the branch heads; they consist of bridges with shutters, placed both across the canal immediately below the departure of the branch, and across the head of the branch itself, the up-stream wings of the two bridges being connected by a curved masonry revetment, and as high as the level of the berm, with a redan-shaped retaining wall, forming an angle equal to that of the departure of the branch, salient to the stream. The two sides of this redan are designed in ghats or flights of steps, which give the means of access to the canal water from the esplanade on a level with the berm; the higher levels or platform corresponding with the roadways of the bridges are reached by stairs laterally arranged in the curved wall connecting the wings.

A first-class choki building is erected on the delta

formed by the main trunk and the branch, the axis being obtained by bisecting the salient angle of the redan: to this axis and at a distance from the angle, varying according to circumstances, the choki building is laid out square and parallel.

The bridges are in all cases furnished with masonry floors in counterarch, resting on deep curtain walls, carried across the canal channel on both the up and down-stream sides of the bridges, and with protective lines either of sheet-piling or walls, the intermediate space being filled with heavy material, on the same plan as has been described elsewhere. The flanks of these bridges are also covered by either piling or retaining walls, and throughout the whole of the series there has been no deviation from the standard plan as originally laid down. The gates and apparatus for opening and shutting are precisely the same as those which have been figured in diagram 73, fig. 1, of the last chapter. They consist of a drop gate 6 feet in depth, which is held in suspension by bar chains fixed to windlasses. On closing the canal, these gates are relieved from their suspended position, by raising the ratchet catches with the end of a marlin-spike, the attached chains being afterwards removed by the hooks being detached from the gates by a lateral movement. Sleepers are dropped one above another on the top of the gate until the bay is sufficiently closed. To close and open one of these bays with the apparatus above described, the time occupied is about 33 minutes; and considering that in the case of the branch heads time is of less importance than it is at the dam regulators, and that leakage is, to a certain extent, of no consideration at all, the establishment that is provided for the working of the machinery will do ample justice to the design, simple as it is, and as it ought to be.

The above is a general outline of the whole of these works, which vary in no material degree beyond that of extent of waterway to the bridges, and in the value of the angle of departure.

The regulator over the main canal at the Futtigurh branch head, has 9 bays of 20 feet in width each, the height of each bay being 17 feet from the flooring to the soffit of the arch. That over the branch head has 4 bays of the same dimensions. The maximum height of water with a full supply in the canal is equal to 10 feet, in which case the lower 7 feet of the branch bays would be closed, so as to admit of the full quota being given to it by an overfall 3 feet in depth, flowing weir fashion over the top of the sleepers. A depth of 3 feet falling freely as in the above case, from a reservoir, would give a discharge per second for each 20 feet opening equal to 352·92 cubic feet, or for four openings 1,411·68 cubic feet per second, the legitimate supply being 1,240. I have not thought it worth while, however, to graduate the discharges below equal depths of six inches; a division which for all practical purposes will, for some time at least, be sufficient. With four bays at the superintendent's disposal, however, he will be able to regulate the discharge in a variety of ways; but when the branch is not required for navigation purposes, the method above described affords the simplest, and at the same time the most accurate measurement.

The width of the roadways of the above bridges is 18 feet, and they provide communication between the town of Mozuffurnuggur and the Sookurtal Ghat on the Ganges, on the high and direct road between the former town and that of Bijnore.

The works are built entirely of brick masonry, from bricks manufactured in native kilns established in the neighbourhood; the size of brick being $12'' \times 6'' \times 3''$.

The grooves for the gates and sleepers are lined with slabs of Agra sandstone, with which the cutwaters in which the bitt heads rest are capped.

The proportions of materials used in the cement are as follow:—

2 parts of Earth Lime.
1 part of Soorkee.

Those for stucco or plaster are:—

1st Coat.	1½ parts Stone Lime. 1 part of Soorkee.
2nd Do.	2 parts Stone Lime. 1 part of Soorkee.
3rd Do.	7 parts best white Stone Lime. 1 part of Soorkee.

The quantity of material and the rates charged for the different species of work, will be found in the following table:—

	Content of Work.		Materials.		
	Cubic feet of masonry.	Square feet of Plaster	Bricks various sizes	Earth Lime.	Soorkee.
				Cubic feet.	Cubic feet.
Masonry	136,046	33,568	1,020,315	45,349	22,671

	RS.	A.	P.	
Arch Masonry	14	8	4	per 100 cubic feet.
Plain "	12	1	5	" "
Plastering	4	9	9·8	per 100 superficial feet.

The total cost agreeably to the bills of the executive officers was:—

	RS.	A.	P.
Masonry	20,262	5	10
Protection Work	6,078	3	2
Earthwork	1,531	1	9
Plastering	1,548	15	6
Metalling	350	4	0
Probable Cost of Work still to be done	4,876	0	0
Total Co.'s Rs.	34,646	14	3

The work was commenced under the supervision of Lieut. E. Fraser, of the Engineers, and completed under that of his successor, Mr. Read.

B. The Bolundshuhur branch leaves the canal on the right bank, at an angle of departure of 60 degrees; it is situated at the 110th mile from the Myapoor regulator.

The bridge over the canal has eight bays of 20 feet in width each, the height of each bay being 14 feet from the flooring to the soffit of the arch. That over the branch consists of one centre bay of 20 feet in width, and two side ones of 15 feet each; the total width of waterway being 50 feet, the height of these bays is the same as that of the canal regulator. The roadways over the bridges are 18 feet in width, and they afford communication between Delhi and Gurmookteesur.

The supply for this branch is equal to 520 cubic feet per second, and the main trunk, after having disposed of this supply, passes onwards in a volume equal to 4,330 cubic feet. The slopes of the channel of both the canal and branch are at the point of separation equal to 15 inches per mile; the soil is of a consistency like that at the Futtigurh head; the foundations, however, are laid in sand, but well protected.

In other respects the detail of construction is similar to that which I have described as the standard for all works of this description.

The maximum high water which will stand upon the regulator at the Bolundshuhur branch head is theoretically equal to 8 feet. For the supply of the branch under such circumstances, it is sufficient to give a superficial flow over the gates and sleepers (which would be adjusted accordingly) equal to 2 feet in depth: this, agreeably to the formula of discharge which has been used throughout these calculations, would be equal to 479·4 cubic feet per second.

These works are, with the exception of the arches, built entirely of blocks of Kunkur, brought from the quarries at Bheel and Dotana. The arches are of brick of the size used at the Futtigurh branch head. The *grooves are lined, and capped* with Agra sandstone slabs, and the whole work is externally stuccoed.

The proportions of material used in the cement are:—

1 part Kunkur Lime to 1-20th of White Stone Lime.

The quantity of material and the rates charged for the different species of work, will be found in the following table:—

	Content of Work.		Materials.			
	Cubic feet of Masonry	Square feet of Plaster.	3 inch Bricks.	Block Kunkur.	Stone Lime.	Kunkur Lime.
				Maunds.	Maunds.	Maunds.
Masonry .	102,817	48,552	282,204	110,132	191	28,621

		RS.	A.	P.	
Rates.	Arched Masonry .	16	0	0	per 100 cubic feet.
	Other Do. .	13	7	0	"
	Plastering . .	2	5	0	per 100 square feet.
	Metalling . .	2	0	0	" "
	Bittheads . .	15	0	0	each.
	Windlasses . .	30	0	0	"

The total cost agreeably to the bills submitted is as follows:—

	RS.	A.	P.
Masonry	14,818	15	8
Plastering	1,122	12	3
Metalling Approaches	210	0	0
Protection	1,555	14	5
Woodwork	1,050	0	0
Required to complete wood and iron work	2,000	0	0
Total Co.'s Rs. .	20,757	10	4

This work was begun and completed by Mr. Philip Volk, the officer in executive charge of the division.

C. The Kool branch leaves the canal on the right at the 152nd mile from the Myapoor regulator. With exception of the bridge over the main trunk having only six instead of eight bays of 20 feet each, the Kool branch works are in every way similar to those at the Bolundshuhur head; the angle of departure and the slope of bed being the same in both cases. The width of roadways is the same, and the distribution of Kunkur and brickwork in the construction of the buildings is in the same proportion.

The Kool branch head affords a cross line of communication between Chundos and Anoopshuhur.

The maximum high water on the Kool regulators, agreeably to the table of discharge, is equal to 8 feet; the supply for the branch is equal to 520 cubic feet per second obtained, as in the case of the Bolundshuhur head, by an overfall on the sleepers of 2 feet in depth; the head itself having a total waterway of 50 feet in width. After disposing of the supply to the Kool branch, the main trunk proceeds onwards, carrying a volume equal to 3,530 cubic feet per second.

The proportions of material used in the cement are as follow:—

1 part Kunkur Lime to 1–20th of White Stone Lime.

The total quantity of material used, together with rates of the different descriptions of work, are shown in the following table:—

	Content of Work.		Material expended.			
	Cubic feet of Masonry	Square feet of Plaster.	8 inch Bricks.	Block Kunkur.	Stone Lime.	Kunkur Lime.
				Maunds.	Maunds.	Maunds.
Masonry .	87,149	45,508	152,445	93,100	286½	25,385

		RS.	A.	P.	
Rates.	Arch-Masonry . .	16	0	0	per 100 cubic feet.
	Other	14	14	8	" "
	Plastering . .	2	3	5	per 100 square feet.
	Metalling . .	2	0	0	" "
	Bittheads . . .	15	0	0	each.
	Windlasses . .	30	0	0	"

The total cost agreeably to the bills submitted is:—

	RS.	A.	P.
Masonry	11,378	1	3
Plastering	1,008	0	9
Metalling Approaches	514	12	9
Protection	2,727	0	0
Woodwork	1,125	0	0
Required to complete Wood and Ironwork .	1,500	0	0
Total Co.'s Rs. .	18,252	14	9

The Koel branch head works were begun and completed under the management of Mr. Philip Volk.

D. *Works at the Nanoon Fork.*

In principle and design these works are similar to those before described. They constitute the heads of the two terminal lines into which the main trunk is divided on its reaching the 180th mile of its course. Whereas, therefore, the Futtigurh, Bolundshuhur, and Koel branch heads may be considered as subordinate to the works on the main trunk, those that I am now about to describe are a component part of it. The position of the two heads with reference to the main canal on its approach to the point of separation, is laid down with a view to obtaining for each of them an equal supply of water. For this purpose, the longitudinal axis of the main canal bears centrically upon the salient angle which separates the two heads; the axis in fact bisects the salient angle, and by so doing, gives an equable adjustment to the current in its bearing upon the two heads. The slopes of the canal bed being equal, viz., 15 inches per mile; the angle of incidence and

departure being adjusted as before described, and the capacities of the bays of the regulating bridges themselves being of equal dimensions; the effects of the wear upon the beds of the channels immediately below the bridges, appear to be the only probable source of disarrangement.

The canal supply on its reaching the Nanoon fork will amount to 3,250 cubic feet per second; and it is supposed that the depth of water under this supply will be equal to 8 feet. It is needless to discuss the methods of regulating the admission of the canal water into the heads of the terminal lines, or to detail the uses that may be made of each separate regulator, further than to say that the means are provided for laying either one or other of the branches dry, and that this can be effected under any amount of supply in the main trunk by the aid of the escapes which lie immediately above them.

The 1st class choki in consequence of the above described position of the axis of the main trunk, and from the form on which the designs of these works are lined out, being built on the axis, has an aspect bearing directly upon the alignment of the main channel. The bridge roadways are 25 feet in width, and they are crossed by the Grand Trunk Road in its passage from Cawnpoor to Alligurh..

These works are, with the exception of the arches, built entirely of Kunkur; the arches are of brick of the usual dimension of $12'' \times 6'' \times 3''$.

The proportions of material used in the cement are as follow:—

1 part of Kunkur Lime to 1-20th of White Stone Lime..

The total quantity of material, as well as the rates at which the work was executed, will be seen by the following table:—

	Content of Work.		Materials Expended.			
	Cubic feet of Masonry	Square feet of Plaster.	3 inch Bricks.	Block Kunkur.	Stone Lime.	Kunkur Lime.
				Maunds.	Maunds.	Maunds.
Masonry .	132,228	43,772	228,400	103,325	105	36,137

		RS.	A.	P.	
Rates.	Arch-Masonry . .	15	0	0	per 100 cubic feet.
	Other . . .	12	0	10	" "
	Plastering . . .	1	13	6	per 100 square feet.
	Metalling . . .	1	9	0	" "
	Bittheads . .	15	0	0	each.
	Windlasses . .	30	0	0	"

The total cost agreeably to the bills submitted is :--

	RS.	A.	P.
Masonry Work	14,884	7	6
Plastering	807	1	7
Metalling Approaches, &c.	2,138	9	0
Protection	2,074	12	10
Woodwork	960	0	0
Required to complete Wood and Ironwork	1,500	0	0
Total Co.'s Rs. .	22,364	14	11

The Nanoon regulators were begun and completed by Lieutenant Merrick, of the 3rd Regiment of Native Infantry, under the supervision of Mr. Philip Volk.

A question may arise as to the advantages or otherwise of having converted the bridges, to which the machinery for regulating the supply is attached, into roads of communication for the public, especially in cases where such roads are the high lines of the country, passed by crowds of people, and open day and night to the constant passage of mail carts and trains of waggons. Before closing this section, therefore, I may, in adverting to the causes which have led to this arrangement, point out that it was obviously one of economy, and that it has been practised elsewhere, although in cases where the amount of traffic was comparatively small. The Kulsea regulator on the Eastern

Jumna Canal lies on the high road between the town of Saharunpoor and the Timli pass, which is the main western gate through the Sewaliks into the Himalayas; it connects Saharunpoor also with the towns of Behut and Raipoor, two of the chief police stations of the district. The traffic over this bridge, although less than that which passes over the Ganges Canal at bridges similarly situated, is considerable; yet the only inconvenience that has been experienced is in the petty pilfering of iron from the sleepers and windlass apparatus; the more probable objections of the working of the machinery being interfered with by the constant passage of men and cattle across the roadway have not been realized. On the Ganges Canal works, including the two regulators of the first section of this chapter, there are six points at which bridges having machinery for regulating the supply are used for the public convenience; of these the Myapoor regulator, and those crossing the terminal lines at Nanoon, are the most prominently connected with extensive thoroughfares.

The Myapoor bridge is the main connecting link between the towns of Hurdwar and Kunkhul, and during the annual fairs is literally not only crowded with people, but is traversed by a continued stream of equipages. At this point it would have been hardly possible, laying economy out of the question, to have had a separate bridge for the convenience of the public; the shutter arrangements, although liable to be called into requisition at any moment, are chiefly for the purpose of keeping the floods of the Ganges River out of the canal channel, and are, consequently, most in use during the rainy months, that is to say, for the four months from June to September: the only cause for their being used at other periods of the year would be on the occasion of floods occurring during the cold weather and at unsea-

sonable periods during the remaining months: accidents to the canal works might lead to either a partial or general working of the Myapoor gate apparatus: but, as a general rule, the active period for its use is during the four months above specified. The great concourse of people takes place during the month of April, at the time of the annual fair, when the probabilities of the gates being called into requisition are exceedingly small. The bridge roadway, being 37′ 9″ in width, is sufficient at all other times to give free room for the working of the gates, as well as for the passage of the public: it was considered, therefore, that there would have been no object in separating the regulating apparatus from the main thoroughfare at this particular point; and as the Kunkhul bridge, which is situated two miles south of the regulator, has been provided for the additional convenience of the towns of Kunkhul and Hurdwar, that further means of cross communication were unnecessary, I do not anticipate the slightest inconvenience either to the works or to the community from the arrangements which have been adopted in this case.

Again, at the Nanoon fork, where the whole traffic between Cawnpoor and Alligurh is carried over the regulators attached to the heads of the two terminal lines, I may observe, that the use of the regulating apparatus will never be so constant, as to cause interruption either to the works or to the community, that as the bridge roadway is made of increased width, and the roads themselves are laid out so as to give the utmost facility of approach, there appears to be no reason why a separate bridge should have been built at a cost of 15,000 Co.'s rupees, for the convenience of the Grand Trunk Road, whilst the present regulators which must have been in close proximity were limited to canal purposes. At any rate considered as an experiment the plan carried out has the merit of economy;

with the advantage (supposing the road authorities find by experience that the communication offered by the present line is an inconvenient one) of leaving the question of building a second bridge for after consideration.

In the four other cases where regulating bridges come in contact with high roads, the absence of extensive thoroughfare renders them of no inconvenience.

The above remarks will show that doubts have existed in my own mind as to the propriety of turning these works to the double purpose to which they have been converted; and there can be no question that economy had very great weight in influencing the determination.

In closing this section of the chapter, it merely remains to point out the views I hold with regard to the establishment which ought to be maintained for the working of the regulators at the heads of branches. I am inclined to place this on the same footing as that of the regulators in the Ganges khadir described in Section I., giving to the beldars the same duties, and making them responsible for the maintenance of the banks, roadways, and esplanades within a defined limit of their post. Under this view of the question, and considering that the maximum number of gates at each branch head, which may be required to be worked at one time, are those over the largest channel, I should define the establishment thus:—

	Number of Gates.		
	Main	Branch.	
1 Futtigurh Head	9	4	4 gangs of 10 men each = 40
2 Bolundshuhur Head	8	3	4 " of " = 40
3 Koel Head . . .	6	3	3 " of " = 30
4 Nanoon Head . .	5	5	2 " of " = 20

This provides four men to each gate, giving in the first three cases a surplus which is desirable from the magnitude of the volume of water, as well as for maintaining the gangs on an equal footing. Each gang of ten men would have a mate, and be subjected to the same discipline, and entrusted with the same duties as are laid down for the establishment attached to the Myapoor and Dhunowri regulators; and (as at those works) the directors' rules and regulations printed in English, Hindi, and *Oordoo*, should be hung up in the public buildings, and posted in conspicuous situations.

III. *Escapes.*

The *Ganges khadir* on its whole length from Myapoor to Roorkee has no works which can be specifically classed under the above denomination. I have before noted that the dams at Myapoor and Dhunowri, although to all intents and purposes capable of affording escape, and therefore used for this purpose whenever required, come more distinctly under the classification of drainage works in the chapter devoted to which they have been described. On all occasions, however, where the supply passing over the Solani aqueduct requires modification, either the sluices of the Myapoor or Dhunowri dam are put in requisition.

It is on the high land of the country, and after the water has passed the khadir of the Ganges that the works which are placed under this section begin to develope themselves. It will be understood that from various causes, especially those relating to local irrigation, and frequently to a somewhat capricious and irregular abstraction of the water from the main channel, the equilibrium which theoretically exists between the supply and the capacity of channel at given parts, must be liable to be disturbed. For instance, theoretically the abstraction

per mile for the purposes of irrigation is uniformly (on *a line of 360 miles), equal to 8 feet per mile, on which* assumption the size of the channel is excavated. It is perfectly clear that on such a long line, extending from the foot of the mountains where the climate is moist, to regions where, hygrometrically speaking, the climate is entirely changed, the demands upon the supply must not only vary with regard to climate and soil, but must be perpetually dependent on local rain-falls, the extent of which in these provinces is very remarkable. These irregularities, necessarily attendant on local causes must be met by efficient remedies, and in this case by providing outlets at stated distances along the line of channel, so that in the event of a superabundant supply (which is observed by a water gauge established for the purpose), the extra water may be passed off and allowed to escape into side channels. I have before alluded to the rajbuha heads and their channels, as the safety valves for maintaining an equilibrium under excess of water; they will undoubtedly act in this respect most beneficially. The works, however, which I am now describing, are specifically for the purpose of regulating the channel supply, and for maintaining it at such a depth as may be most convenient to the works, or most useful to the cultivators. In designing these works I have laid down the following rules for my guidance; and although from local causes they have not always been strictly attended to, they have been followed to an extent sufficient to meet the purposes which are contemplated.

1st. With reference to "position," I have limited the distance between the escapes to 40 miles, considering that by adapting their capacity for outlet to the volume of water contained in the 40 miles of channel to which they are intended to provide the means of escape, the facilities for regulation will be ample.

2ndly. In the sandy tracts which constitute the elevated region lying above the Ganges and West Kalli Nuddi; to multiply the number of escapes rather than to *increase their waterways; to encounter the difficulties of* contending with large volumes of water in detail, rather than in mass; and to facilitate and ease off the passage of the escape-water by length of channel, as well as by artificial protective expedients.

3rdly. To fix the sites of all escapes in such a position that there may be a plunge into the bed of the receiving channel, and that the high-water mark of the latter may in no case interfere with the free discharge of the water from the canal.

4thly. To make the escape buildings a component part of other works,—or, should this not be possible, to *place them in such close proximity to bridges and chokies,* that they may be easily accessible and properly looked after.

5thly. Independently of original excavation which is devised simply on economical principles; that the escape channel when perfected shall, in addition to the initial slope of 12 inches from the bed of the main channel, which is given to the tail of the escape head, have a *slope of bed equal to 1·5 feet per mile, the superfluous* slope being overcome by permanent works in masonry, adapted to the particular circumstances under which the escape channel is situated.

From Roorkee, therefore, downwards, the sites of *escapes for the relief of the canal channel have been* determined on the above principles, unless there have been reasons which will be fully explained, for their having been departed from.

It will be advisable for the sake of distinctness to divide the escapes under different heads.

A.—Those on the main trunk between Roorkee and Nanoon.

B.—On the Cawnpoor terminal line.

C.—On the Etawah do. commencing with A, we have on the main trunk:—

1.	The Khutowli Escape	. .	62nd mile.
2.	Muhummud Aboo's Escape	.	69th do.
3.	Janni Khoord do.	. .	87th do.
4.	Moondakhera do.	. .	141st do.
5.	Kasimpoor do.	. .	166th do.

Five different works, situated at distances from the Myapoor regulator, as shown above.

Now, the three leading items, viz., the escapes at Khutowli, Muhummud Aboo, and Janni Khoord, are for the relief of the channel at points where, from the large volume of water that it has to carry, and from the nature of the soil through which it is conducted, most especial care is required. These three escapes may be considered under the second head of my rules for guidance, as two outlets divided into three separate lines: their width of waterway in the aggregate is equal to 180 feet, and as separate works, they provide a discharge of 60 feet in width; each work consists of ten bays or sluices of 6 feet in width each; and they each throw their water into the valley of the West Kalli Nuddi, under circumstances peculiarly favourable with reference to declivity of channel, although from the sandy nature of the soil through which the bed is excavated, and the amount of fall to be overcome by masonry works, the completion of these escape lines will be a heavy item in the expenditure.

Taking these three escapes in the order of their precedence, we first pass in review:—

No. 1.—The Khutowli Escape.

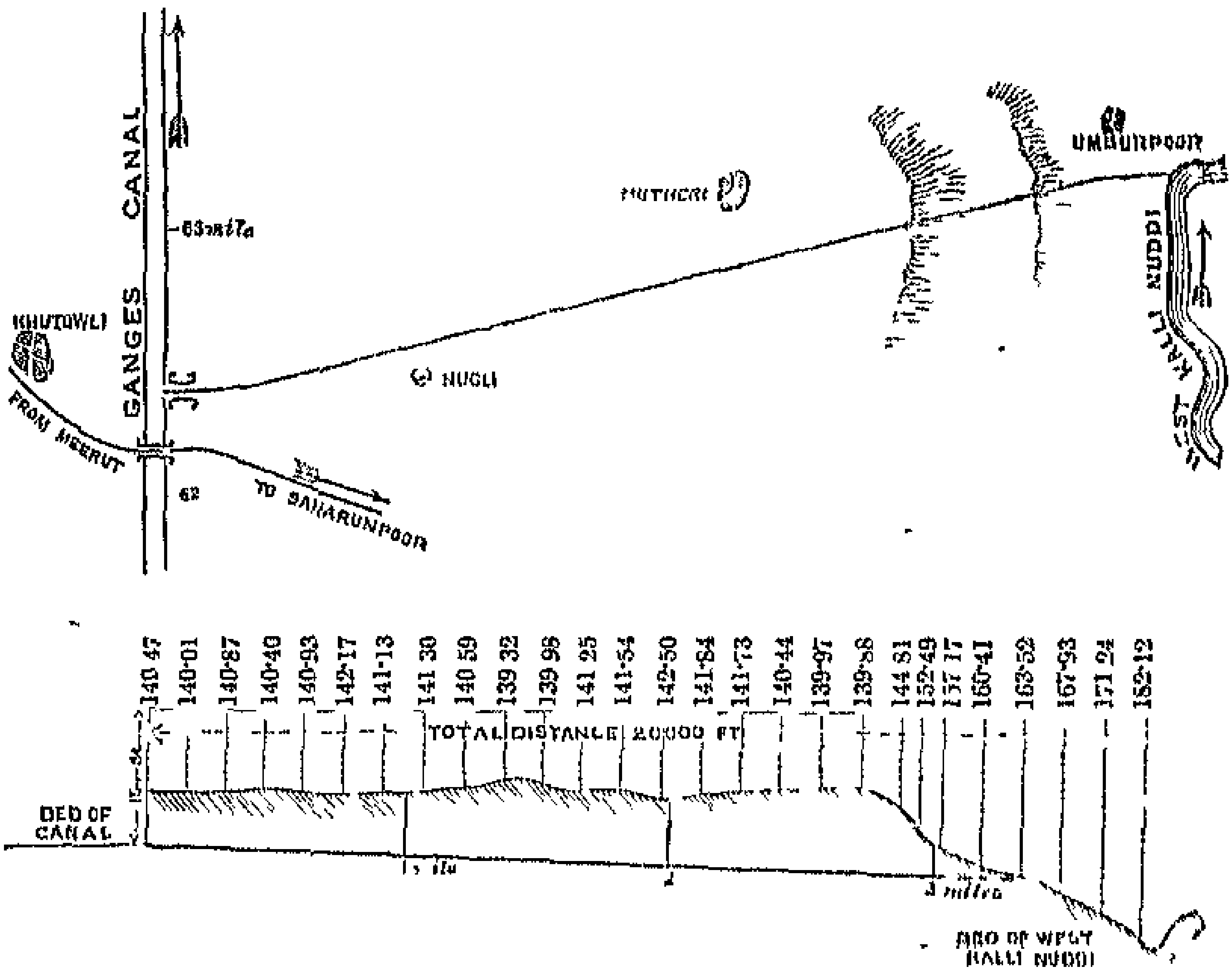
This building is situated on the right bank and on the down-stream side of the Khutowli bridge, or that

on the high road between Saharunpoor and Meerut. The axis of the bridge and escape are separated by a distance of 550 feet.

The West Kalli Nuddi, with which the canal is connected at this point by an excavated channel, 60 feet in width at its head, decreasing to 20 feet at its tail, lies at a distance of 3⅜ miles. Advantage was taken of a ravine or tributary, which extended inland for some distance, to reduce the length of digging, by leading the line to its head. The map and section of this portion of the work are shown in the following diagram:—

Diagram 93

KHUTOWLI ESCAPE



The total fall from the bed of the canal to that of the West Kalli Nuddi is 29·21 feet on a length of 20,000 feet, or 3 miles 6 furlongs and 290 feet, the

total fall per mile being 7·71 feet. To have completed this line with properly regulated slopes, and with the necessary works for disposing of the superfluous fall, would have been a work of considerable time, and an undertaking demanding labour, and it would have occupied the attention of the supervising establishment in a way that would have led to interruption to the works of the main canal line, upon which more immediate progress was indispensable. I therefore determined, after clearing out the channel, so as to admit of a free passage for the escape of water, to postpone the execution of the permanent works for the correction of the slopes, until the current, by acting on the bed, had by its natural retrogressive excavations, given us fixed points for establishing the masonry descents. The saving in expense, by thus permitting nature to perform the duties which we must otherwise have done by labour, is very great; and from the character of the work, and our ability to regulate the water passing along the channel, or even stop it altogether, there could be no fear of accidents or disarrangement; the plan under such circumstances was quite a legitimate one, and I have practised it universally in all the escape channels connected with the Ganges Canal works.

Instead, therefore, of carrying the excavations on an uniform slope of 1½ feet per mile, until the bed level struck upon the slope of the valley, the above slope was given to the leading mile of its course only, or up to a point where the channel is crossed by the main right rajbuha, to which a bridge of cross communication is attached: from this point the excavation was carried on a dead level, by which 1½ feet in depth per mile was saved. The bridge attached to the rajbuha has at its down-stream side an overfall of 8 feet in perpendicular depth, constructed in the usual form, protected

by flank and tail defences, and in every way ready to meet the action of retrogression. It will be understood that, by the above arrangements, out of the total fall of 29·21 feet from the canal bed to that of the river, we only dispose of 1 foot, the amount of tail fall to the escape head, $1\frac{1}{2}$ feet to the slope for one mile of escape, and 8 feet for the masonry descent, or a total of $10\frac{1}{2}$ feet: the remaining slope having to be regulated by an amount of masonry descent equal to 15 feet, the balance being disposed of in the slope of the earthen channel. With the profile of the country before us, and knowing the slopes upon which it is our intention to regulate the bed of the escape channel, it is obvious that the engineer can determine the precise position in which, when the current has made its own excavations, the additional masonry descents will have to be built; he, therefore, has collected on the spot material sufficient to execute the work with the greatest promptness, so as to preclude all chance of the works which are situated in the rear being injured.

I have in the above section noted the precise points at which the falls may be built hereafter, placing as great a distance between them as possible; the most economical material to use in the construction of these works will be masonry: by building them of the best brick and kunkur work in the first instance, repair will be saved hereafter, as their position, detached altogether from the main line of works and consequently of patrol, will render them liable to less supervision than would otherwise take place. I need hardly dwell on the necessity of periodical examinations of works of this sort, both by the executive officer and the director of the works.

The disposition of slopes and works on the Khutowli Escape, with the necessary data on which they were arranged, may be thus explained:—

Length of channel from main canal to the West Kalli Nuddi		Feet. 20,000
Total fall from the bed of canal to the bed of river		29·21
Slope at 1·5 feet per mile	5·68	
Tail slope of escape head	1·00	
		6·68
Balance to be disposed of in masonry falls		22·53
Of this in rajbuha bridge	8·0	
At 2 points intermediate between the rajbuha head and the West Kalli Nuddi, 2 falls of 7½ feet each	15·0	
		23·00

It is desirable that the masonry descents should be placed at as great a distance from each other as possible, so as to prevent the accumulation of velocity on the heads; and to secure this, the above rule of placing the falls equidistantly is probably the best; in practice, however, the falls are in all cases connected with bridges, so that their position on the escape depends in a great measure on the high roads of the country. In all cases where the depth of channel is sufficient, I have designed the waterways of these bridges in one bay of 50 feet width.

The total cost of the excavation on the above work was Co.'s Rs. 20,805-8-5, at a rate equal to Co.'s Rs. 1-10-5·6 per 1,000 cubic feet.

The masonry head consists of 10 openings of 6 feet in width each, their height from flooring to the soffit of the arch being 8½ feet; the flooring is raised 2 feet above the canal bed in gradations depending on the working of the gates and sleepers. The transverse width of the flooring is equal to 64 feet, 40 of which form the tail which is laid on a slope (inclining down-stream) of 1 foot from the level of the canal bed. The flanks of this work are protected by masonry revetments, and the usual guards of piling and rubble work, with which the floorings are also covered and protected from the wear and tear of

the current on its approach and departure, by box-work aprons.

In consequence of the magnitude of the canal embankments at Khutowli, and the elevation of their upper esplanade, which is 20½ feet above the canal bed, the apparatus for opening and shutting the sluices has been covered by a line of building, the roof of which corresponds with the higher levels, and, therefore, acts as a roadway, without interrupting the communication on the bank. The supports for the windlasses, which consist of upright timbers placed in the form of a cross, act also as supports to the roof, and give great additional strength to the building. It will be seen by the plan, Plate XXXVII., that the chains attached run over an upper roller, by which the whole waterway is relieved, by the gate being drawn up through the slit made in the flooring, and raised as high as the roof: the design is of the simplest description, it is exceedingly strong, and from its being protected from the weather, and from disturbances arising from other causes, it is hoped that the working will be very efficient.

This work is built with a combination of old and new brick, with cement consisting of the following ingredients:—

2 parts of earth lime.
1 part of Soorkee.

The total quantity of material used is equal to :—

433,867 bricks of various sizes.
19,283 cubic feet of lime (earth).
9,641 „ of Soorkee.

And the rates at which the work was executed were as follow:—

	RS.	A.	P.	
Masonry	13	7	11	per 100 cubic feet.
Plaster	2	3	7	per 100 superficial feet.

This escape was begun by Lieutenant Fraser of the Engineers, and completed by Mr. Read, under whom the adjustment of the machinery has been managed. Its total cost was, excluding regulating apparatus, Co.'s Rs. 11,778-2-9.

No. 2.—Muhummud Aboo's Escape.

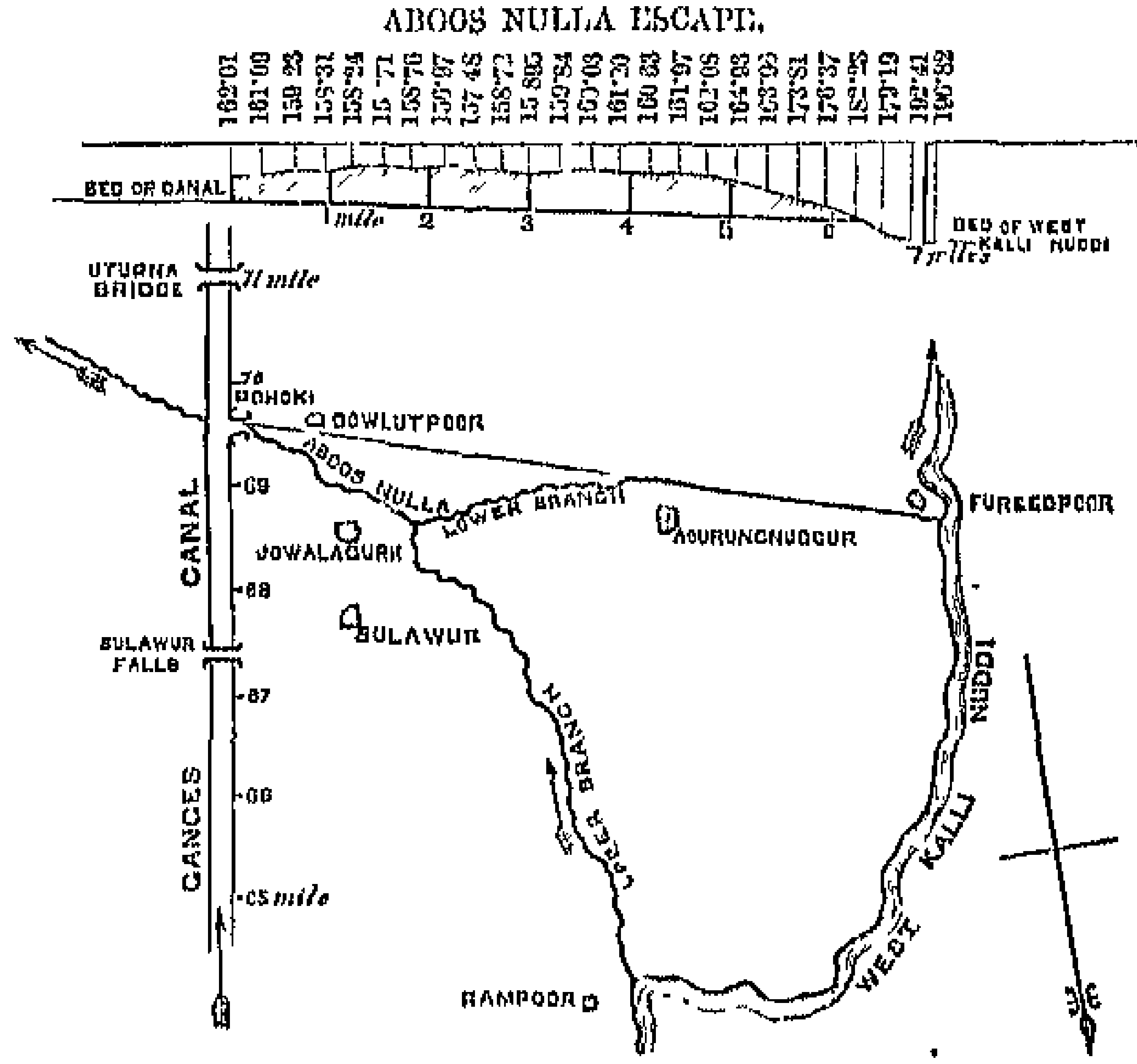
The building at the head, with the exception of the covered in accommodation for the machinery, and the superstructure appended thereunto, is the same as at Khutowli; the bays, however, are 13 feet in height from the flooring to the soffit of the arch. The sluice gates, which are of the same description as those at Khutowli, are worked by windlasses resting in the plain bittheads common to the canal works in these provinces. They are protected by a second-class choki which is in close proximity to the work.

The site of Muhummud Aboo's Escape is on the right bank of the canal between the 69th and 70th mile of its course from the Myapoor regulator. It is the most awkwardly situated of the whole of the canal works, being separated by a considerable distance from bridges of cross communication. From being on the opposite side of the canal to that upon which the high road runs, access to it can only be gained by crossing the canal, either at the Salawur or at the Uturna bridges; from the former it is 13,265 feet distant, and from the latter 7,960 feet. It would be desirable, perhaps, to maintain an open road along the right bank of the canal as well as on the left, between the Salawur Falls and the Uturna bridge, by which means free access would be given to Muhummud Aboo's Escape, and the communication with this building, which is now rather awkward, would by these means be perfectly facilitated.

The channel, as its name indicates, is a portion of the ancient canal dug by Muhummud Aboo Khan. As will be seen by the plan in the following diagram, we have taken possession of the lowest of two lines which appear to have been formerly used as heads for the canal; the levels of our escape being carried in a counter-direction towards the river, which it joins under Fureedpoor.

Diagram 94.

ABOOS NULLA ESCAPE.



The disposition of slopes and works which are required for this line of escape will be explained by the following:—

		Miles. Ft.
Distance from the canal channel to the West Kalli Nuddi		7 311
Total fall from bed of canal to bed of river .		23·93 feet.
Required slope:—		
From the tail at escape head . . .	1·00	
Channel slope on 7 miles at 1·5 ft. per mile	10·50	
		11·50
Balance, superfluous slope		12·43 feet.

To which it would be sufficient to give two descents of 6 feet each, admitting of two bridges of cross communication, to one of which the line of right main rajbuha would be attached. I have, under the head of the Khutowli Escape, stated that in all cases where the depth of excavated channel will admit of it, I have designed the waterways of these bridges and falls in one bay of 50 feet in width, with a segmental arch of 60°; this in round numbers gives a versed sine or rise to the arch of 7 feet, which with the height of pier, and thickness of arch, and superstructure connected with a super-passage channel for the rajbuha, necessarily limits this dimension of arch to certain localities, where the depth of digging is great, and where the bed of the rajbuha lies on a high level. By doubling the number of bays and reducing the width of each to 25 feet, we diminish the versed sine to 3½ feet, and reduce it to one-half of that of the large arch, and by these means are enabled to reduce the height of the superstructure, and to adapt it to the section of the excavated channel. I would in no case reduce the waterways of the bridges below 50 feet in width, as independently of the escape water from the canal, the channel will hardly pass through so long a tract without receiving in its course a considerable quantity of country drainage.

The design upon which Muhummud Aboo's channel has been excavated, is the same as that practised at Khutowli. The leading mile has been excavated on a slope of 1·5 foot per mile, from which point it is carried on, on one uniform level, nature being allowed to work her own progress in retrogression of wear, and the engineer having to meet the retrogression by the establishment of permanent works. Here, as at Khutowli, the leading bridge with its fall is attached to the main rajbuha, which is at the time that I am now writing in the course of construction. The natural wear upon the bed, therefore,

will take place between the West Kalli Nuddi, and the down-stream side of this bridge, precisely as is the case at Khutowli; in that instance, however, two intermediate falls have to be constructed, in the present there is only one.

The capacity of channel as excavated is reduced to the most economical limits, being in rectangle 60 feet in width on the 1st, 40 on the 2nd, and 20 feet in width on the remaining miles of its length, the side slopes being at an angle of 45°.

The cost of this excavation was Co.'s Rs. 34,807-6-8, at a rate per 1,000 cubic feet equal to Rs. 1-9-6·8.

The *head-work is constructed of kunkur and brick* masonry, the disposition of the material being the same as that universally adopted in this division of the works, where kunkur is procurable. Kunkur being used in the floorings and most massive parts, and brick elsewhere.

The proportions of material used in cement are as follow:—

2 parts of earth lime.
1 part of Soorkee.

The quantity of material expended, and the rates at which the different species of work were executed will be seen by the following table:—

RATES OF WORK.

	RS.	A.	P.	
Masonry	12	8	6	per 100 cubic feet.
Plaster	3	0	3	,, superficial feet.

MATERIALS EXPENDED.

425,640 bricks of various sizes.
18,918 cubic feet earth lime.
9,450 ,, Soorkee.

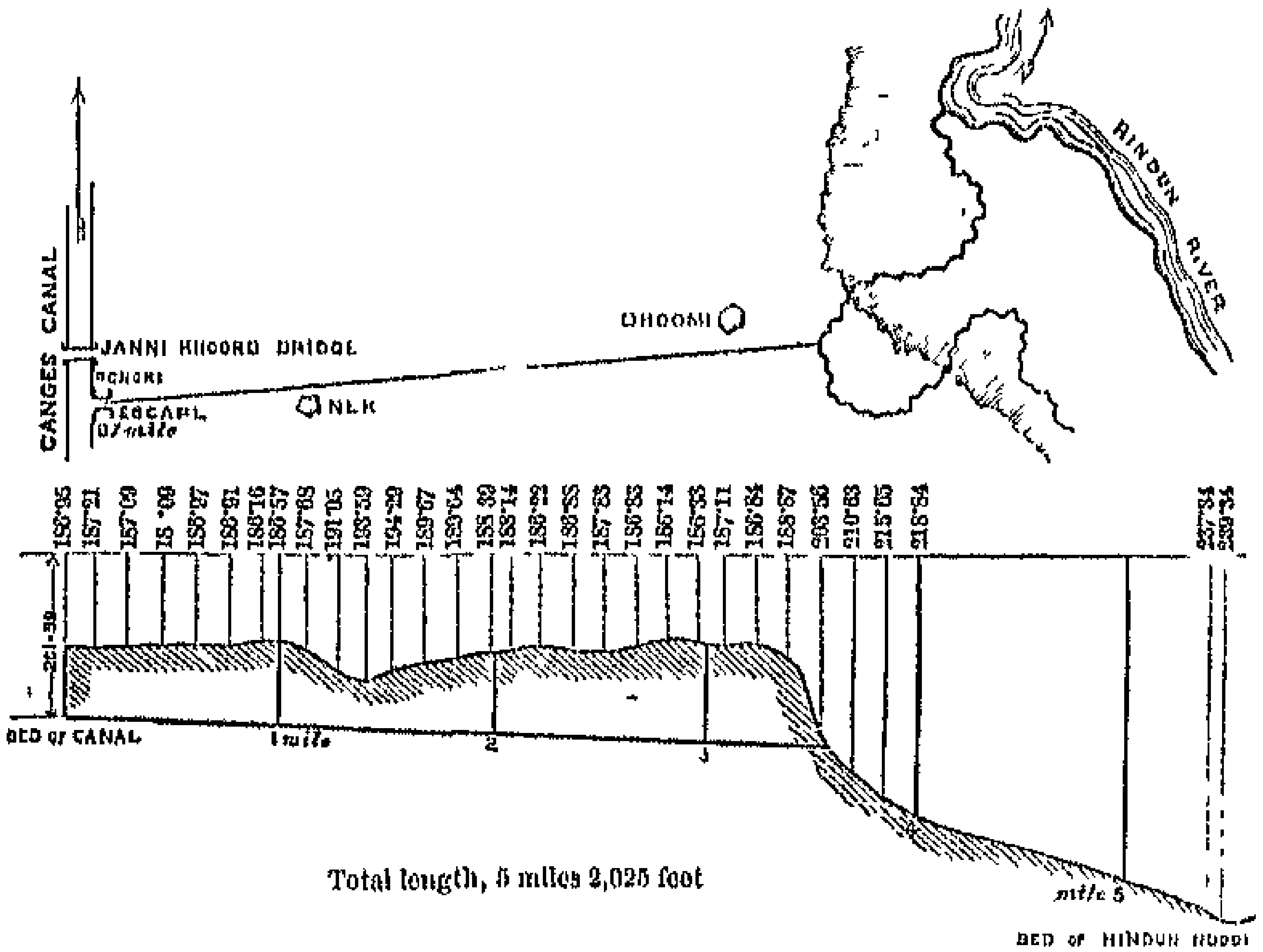
Muhummud Aboo's Escape was begun and completed by Mr. Read, the executive officer of the 2nd division of the works. Its cost was, excluding the cost of regulating apparatus, Co.'s Rs. 10,487-11-7.

No. 3.—Janni Khoord Escape.

This as the third of the series of escapes attached to the upper portion of the main trunk on its passing over the high land of the Doab, is built precisely on the same plan and with the same extent of waterways, sluice arrangements, &c., as has been explained at the others; it corresponds, however, with Muhummud Aboo's Escape in regard to want of cover for the windlass apparatus, and absence of superstructure connected with it. The height of the sluice openings from the flooring to the soffit of the arches is equal to 11½ feet, and their regulating apparatus is precisely similar to that at Muhummud Aboo's outlet.

Diagram 95.

JANNI KHOORD ESCAPE.



The head is situated on the right bank between the 87th and 88th mile, and at a distance of 1,130 feet from the up-stream side of the Janni Khoord bridge; a second-class choki is built intermediately between the bridge and

the escape, for the purpose of affording protection to the latter work, and of keeping the establishment on the spot.

The excavated channel is similar to that before described, and its design with reference to natural abrasion is the same.

The map of the country, with the profile of the line upon which the excavation has been carried, are shown in the preceding diagram.

The escape channel joins the Hindun River at a point in its course, 20 miles below the junction of the West Kalli Nuddi; at this point the bed of the Hindun is 38·06 feet below the bed of the canal, a difference of level which will lead to works of a more extended description than those before described at the Khutowli and Muhummud Aboo's escapes.

The disposition of works depending on this excess of slope will be as follows:—

		M. f. ft.
Distance from the canal to the Hindun . .		5 3 415 (say 5 miles.)
Total fall from the bed of the canal to the bed of the Hindun River		38·06 feet
Required slope for the tail of escape head	1·0	
Slope of channel at 1·5 feet per mile .	7·5	
		8·50
Balance, superfluous slope . . .		29·56 feet.

To overcome which four falls of 7½ feet will be required. Of these four falls, the leading one, or that nearest to the canal would be adapted to the passage of the main right rajbuha, and the remaining three would occupy positions at intermediate distances, providing the means of cross communication by bridges.

The excavated channel is in progress at a rate of Rs. 1-8-0 per 1,000 cubic feet.

The head-work is, as in the case of Muhummud Aboo's Escape, built of kunkur and brick, the former being con-

fined to the foundations and the massive parts of the structure.

The proportions of material used in the cement are as follow:—

2 parts of earth lime.
1 part of Soorkee.

The total quantity of material expended, and the rates charged for the building, are exhibited in the following table:—

521,010 bricks of various sizes.
23,156 cubic feet of earth lime.
11,578 „ of Soorkee.

	RS.	A.	P.	
Masonry, including plaster .	14	7	11·8	per 100 cubic feet.

The Janni Khoord Escape head and excavated channel were commenced and are being completed under the supervision of Mr. Read, and cost, exclusive of the regulating apparatus, Co.'s Rs. 13,204-3-7.

The above gives a general outline of the three escapes to which I have before alluded, as combining in themselves a relief to the main channel in its passage through the early and sandy districts of the high land of the Doab. It will be understood from what I have before said, that the works as at present constructed consist of an escape head attached to the canal embankments, and a passage for the right rajbuha, the latter being connected with a bridge of communication and with a masonry fall for the purpose of overcoming superfluous slope. The channels of escape have also been excavated so as to admit of an open passage for the water, and to give free scope to the objects for which they were designed. The works in all three cases are completed as far down the channel as the bridge over which the rajbuha passes, and to which is appended the first masonry descent; beyond this point operations for the present have ceased; the

completion of the remaining overfalls, and the adjustment of the remaining slopes, being left until the action of the current has cleared the channel sufficiently to admit of it.

In recapitulating the works attached to the three escapes above described, the following table will show the work that has been completed, and that which remains to be done as opportunity offers :—

	Total required.		Built or in progress.		To be built hereafter.	
	Head.	Falls.	Head.	Falls.	Head	Falls.
Khutowli Escape . . .	1	3	1	1	...	2
Muhummud Aboo's Escape	1	2	1	1	...	1
Janni Khoord Escape .	1	4	1	1	...	3

There are, consequently, six masonry descents remaining to be built after the escape channels have been brought into use; of these, two at Khutowli have a fall of 7½ feet each, that at Muhummud Aboo's Escape of 6 feet, and finally three at the Janni Khoord Escape, equal to 7½ feet each; the full waterway being 50 feet in width, either in one or two bays, as may be most convenient to the particular site on which the work is to be built. The plans and sections of these overfalls are shown in Plate XLVII. of the Atlas.

No. 4.—Moonda Khera Escape.

Passing by the head of the Bolundshuhur branch at the 110th mile which may be considered as capable on emergencies of performing the duties of an escape, we arrive at the Moonda Khera outlet, lying at the 141st mile, and at the head of the rapid descent which takes place in the canal levels at the lower extremity of the main trunk.

The Moonda Khera, and its neighbour the Kasimpoor Escape, are to the lower what the three escapes before described, are to the upper tract of the main canal in its passage over the high land of the country.

The influence that these two works exert upon the regulation of the supply in the terminal lines into which the main trunk is separated at Nanoon has been elsewhere adverted to; that now under description I may repeat, provides the means of relieving the canal on occasions when the Bolundshuhur branch is thrown out of use, and its water is turned into the main trunk, which it also relieves from a large body of water at a point before it reaches the lower levels in the neighbourhood of Alligurh. The Moonda Khera Escape gives facilities also for repair to the masonry descents and works connected with them, which lie on its down-stream side.

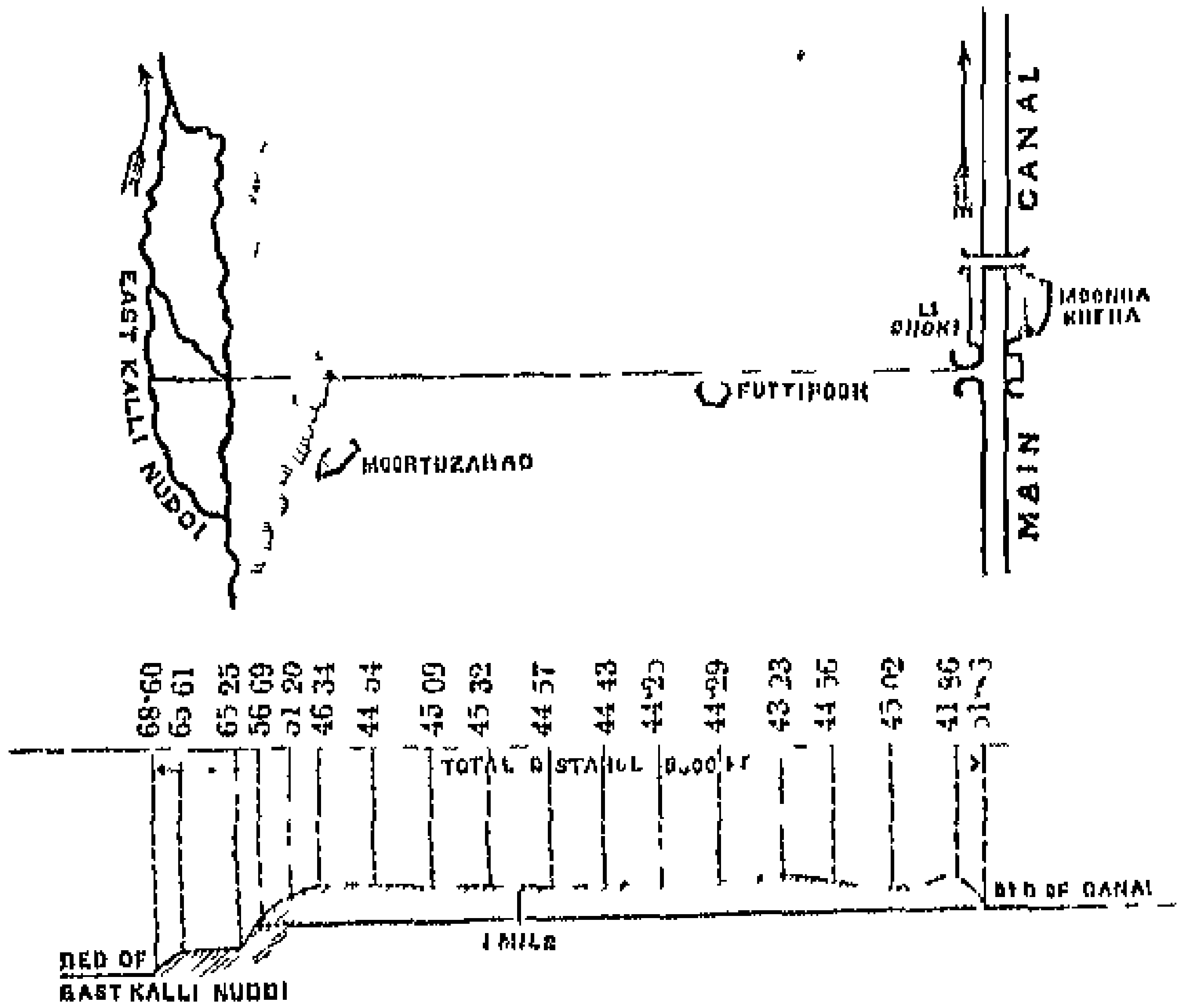
At the point of the canal where this work is situated, the alignement has deserted the valley of the Jumna and its dependent tributaries, and is in close contact with the East Kalli Nuddi, the river which provides drainage to the most northerly flat of the Ganges. For a distance of 10 miles in the neighbourhood of Moonda Khera, the East Kalli Nuddi and the canal run in close proximity, separated from each other by a tract of country not exceeding 2½ miles, and at a point near the village of Mamun, about 1½ mile in width.

The site at Moonda Khera was selected as being convenient from its proximity to the site of a first-class choki post, and to the country lying between it and the river being well adapted for the excavated channel.

The following plan and profile will, with the figured description of the disposition of slopes and works offer a fair explanation of the value of this escape, it being understood that the arrangement before described of

leaving the current to act upon the bed under prescribed limits is still continued.

Diagram 96.
Moonda Khera Escape.



Distance from the main canal to the bed of the East Kalli Nuddi		9,500 feet
Total fall from bed of canal to bed of East Kalli Nuddi		16·74 „
Tail slope for escape head	1·00	
Slope of channel at 1·5 feet per mile .	2·69	
		3·69 „
Balance, superfluous fall		13·05 feet.

To which two masonry descents, each with a drop of 6½ feet, would be required. The leading descent, which will, I imagine, be built near the village of Futtipoor, will have the super-passage channel of the main left rajbuha attached to it—the second fall will be established near the village of Mootazabad, near the crest of the high land on its descent into the valley of the river. A width of waterway equal to 30 feet ought to be given to the bridges which cross the escape. The channel has been excavated on a width of 50 feet, and a bed slope of 1·25

per mile. The soil is of a tenacious quality, and as such is very superior to that with which the upper escape was connected.

The head of this line of escape forms a component part of an extensive series of works connected with the Moonda Khera Bridge; its axis is separated from that of the bridge by a distance of 434¼ feet; it lies on the left bank and is joined to the bridge itself by a line of ghats or steps, which meet the face of the bridge in an ogee curve; similar ghats and works of protection to the right and opposite side of the canal are also built in correspondence with those on the left.

The bridge which lies at a distance of 1½ mile or thereabouts from the town of Khoorja, acts as the main line of communication between that town and the country on the left bank of the East Kalli Nuddi. Between the bridge and the escape head, and in the centre of an esplanade is a first-class choki building; the works are considerable in extent, and will, I think, be found to be conveniently situated.

The design of the head differs in detail from that of works before described. As built on the left or road side of the canal, and consequently connected with the towing path, it was necessary to maintain an unbroken passage along the berm. In this region of the works, moreover, the quantity of earth excavated from the channel did not necessitate the raising of the embankments to an immoderate height, leading to the deformity which exists more or less on the whole tract extending from Myapoor to the 110th mile. At Moonda Khera the section both in berms and esplanades is equably formed, and the earthwork is altogether of a more compact description, and of a more uniform character than it is in the upper districts. The above advantages, added to the towing-path arrangements, have, as I said before, led to modifications of the plan

before described. The sluices, ten in number, and each of them 6 feet in width, are arched over, both on the full width of the berm and roadway, so that a free passage is open on both—the former being on a level with the earthen berm, and consequently depressed to an extent of 2 feet below that of the roadway.

The sluice gates are worked by windlasses and the usual apparatus, through slits or apertures situated between the berm and the bank on the canal side. The cutwaters also which lie at the mouths of the sluices are fitted with grooves for sleeper planks. The tail flooring, or that which lies on the down-stream side, and towards the escape channel, is 40 feet in length, on the full width of the work; the flanks on the right and left of the tail are raised to a height of 12 feet, so as to admit of the upper esplanades being retained on equal levels. A plan of this work is given in Plate XXXVIII. of the Atlas.

The masonry, with the exception of archwork, and finishing, consists entirely of block kunkur; the cement which was used being of the following proportions:—

1 part Kunkur lime to
1-20th of white stone lime.

The Moonda Khera Escape head is a component part of the bridge and ghats at that place, in the cost of which it is included. The following are the rates at which it has been executed:—

	RS.	A.	P.	
Arch masonry	15	0	0	per 100 cubic feet.
Other "	10	0	11	" "
Plastering	2	5	8	per 100 superficial feet.
Metalling	2	0	0	" "
Bitt-heads	15	0	0	each.
Windlasses	10	0	0	each.
Earthwork of escape channel	1	4	0	per 1,000 cubic feet.

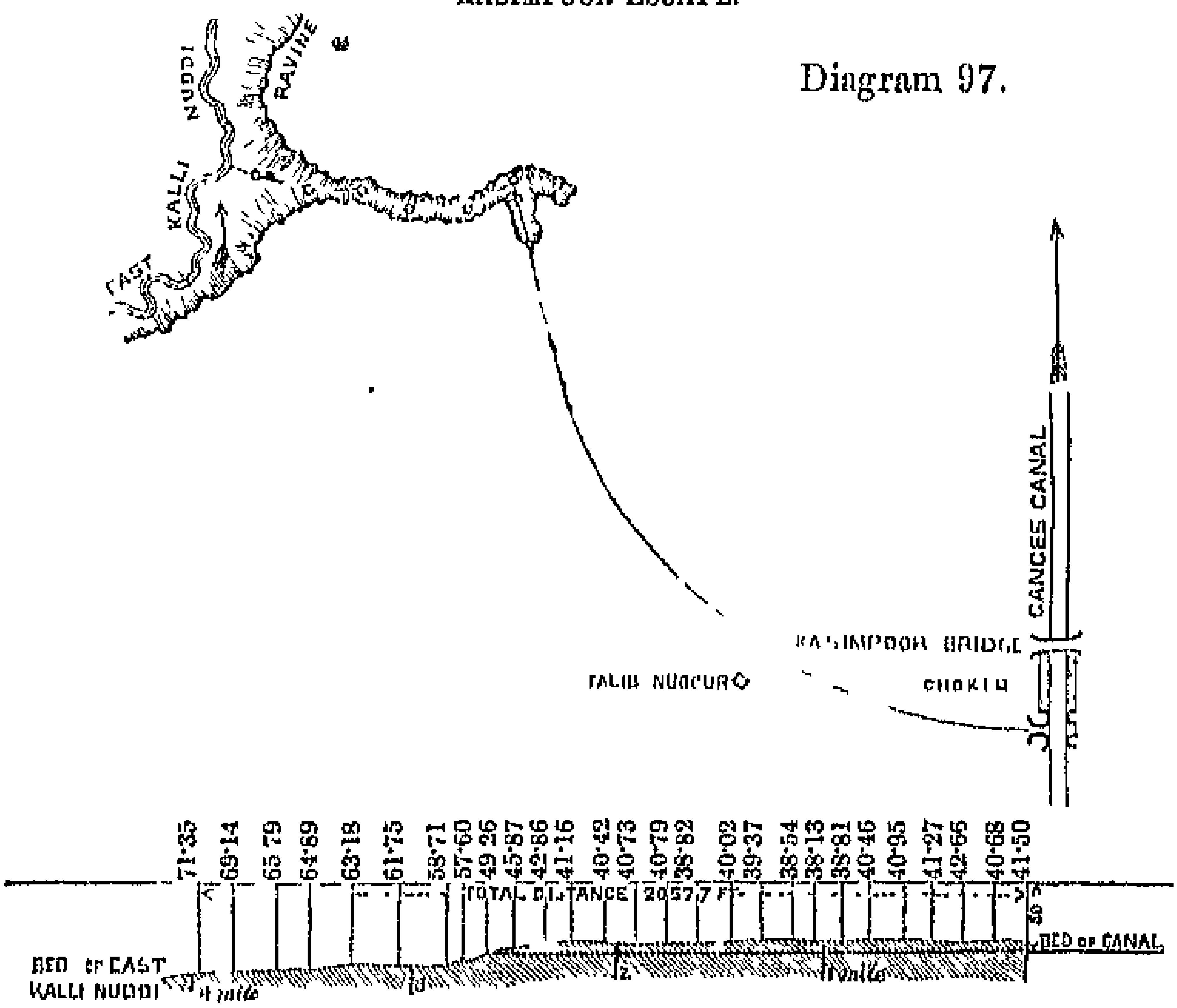
No. 5.—Kasimpoor Escape.

This work is in all respects similar to that at Moonda Khora; it has the same extent of waterway, and its situation relatively to the Kasimpoor Bridge is in all its details connected with ghats, choki accommodation, &c., similar.

The escape is on the left bank at the 166th mile of the course of the main canal, and immediately below the falls at Pulra and Simra: its position is intermediate on the line extending from the Simra falls to the Nanoon regulators.

KASIMPOOR ESCAPE.

Diagram 97.



The especial duties which the Kasimpoor Escape is intended to perform, are, first, the relief of the canal from excess of water arising from the supply of the Koel branch head being thrown into the canal channel; secondly, the regulation of the supply into the terminal lines into which the main trunk is divided at Nanoon. Connected with the Moonda Khera Escape, it perfects the

means of relieving the canal channel from excess of water in the lower regions of the main trunk.

The preceding diagram shows the line of country which is crossed by the escape in its passage to the East Kalli Nuddi.

Distance from main canal to bed of East Kalli Nuddi		20,577 feet.
Total fall from bed of canal to bed of East Kalli Nuddi		21·35 ,,
Tail slope for escape head	1·00	
Slope of channel at 1·5 feet per mile .	6·00	
		7·00 ,,
Balance, superfluous slope		14·35 ,,

This will be disposed of in the usual way, the leading fall being connected with a superpassage for the left main rajbuha. The remaining descents will be constructed hereafter, when the effects of retrogression of levels render such works necessary. The soil, at least that part of it which is connected with the high land, is firm and tenacious; sand I imagine alone exists in the valley of the East Kalli Nuddi.

The channel has been excavated on a width of rectangle equal to 50 feet; the bed slopes have been laid out at 1·25 feet per mile.

The Kasimpoor Escape is proposed to be attached to the divisional charge of the officer who holds the terminal lines. It will constitute the head of his division, and will give him the power of regulating the supply of water required for his irrigation.

The method of construction of the Kasimpoor Escape head, and the description of material used, are the same here as at Moonda Khera; the proportions of ingredients used in the cement being as follow:—

1 part kunkur lime, to
1-20th of white stone lime.

The Kasimpoor Escape head is (as at Moonda Khera) a component part of the bridge, ghats, &c., at that place, in the cost of which it is included: the rates of execution are as follow:—

	RS.	A.	P.	
Arch masonry . . .	15	0	0	per 100 cubic feet.
Other masonry . . .	10	1	3	" "
Plastering . . .	2	11	11½	per 100 square feet.
Metalling . . .	2	1	6	" "
Bitt-heads . . .	15	0	0	each.
Windlasses . . .	10	0	0	"
Earthwork of escape channel	1	5	0	per 1,000 cubic feet.

The work was commenced and completed by Mr. Philip Volk. The five escapes above described embrace the whole of the works, which are specifically designed for regulating the irrigation supply on the tract from Roorkee to Nanoon. Their disposition on the line of canal is in some degree connected with the heads of the branches, from which they derive in all cases very material assistance, and a support, which as being mutual, adds considerably to the efficiency of both. The command that these works have over the rivers into which they discharge their surplus water is in all cases a security against interruption at any season of the year.

B. *The Escapes on the Cawnpoor Terminal Line.*

Under this section are included all the works for regulating the supply between the Nanoon regulating head and the works at Dubowli, the latter being included in the list of terminal works appended to the descent into the Ganges at Cawnpoor.

It will be observed by the map and the position in which the Cawnpoor line of canal is placed with reference to the rivers on its right and left, that the facilities for disposing of its escape water are by no means so good as

those which attended upon the main trunk in its passage to Nanoon. The East Kalli Nuddi, by taking a wide departure from the bearing upon which the canal runs, is at too great a distance to be made conveniently available, whilst an intervening river, the Eesun, which rises on the left almost immediately after the canal leaves Nanoon, separates the canal from the East Kalli Nuddi entirely. On the right, the line of canal is accompanied on the greater part of its course by the Rinde, and the Pandoo rivers, which, like the Eesun, continue for many miles in the early part of their course in a shallow bed, ill adapted both from slope and capacity of channel for affording relief to the canal supply.

Advantage to a limited extent has been taken of the East Kalli Nuddi, and whilst avoiding the channels of the Rinde, the Eesun, and the Pandoo, as far as it was possible, in those parts of their courses which were most especially open to the inconvenience above referred to, we have used them at more advanced points where the elements required for efficient canal escape were comparatively speaking of a higher order.

The escapes on the Cawnpoor terminal line are as follow:—

1. The Ginnowli Escape at the 9th mile.
2. ,, Nugaroea do. . 49th do.
3. ,, Tiroea do. . 87th do.
4. ,, Kukwan do. . 135th do.

The Dubowli Escape, which is situated at the 165th mile, and is the head of the Cawnpoor terminal works, is, as I have before said, included in the chapter devoted to those works; its existence, however, may be noted here, as a work which perfects the chain of escapes on the terminal line connected with the Ganges.

1.—The Ginnowli Escape Head.

The channel with which this work is connected is more specifically for the purposes of drainage than for regulating supply; its object is to provide relief to certain low tracts of land on the left of the canal bank, which were, previously to the excavation of the canal, directly connected with the drainage of the Rindo, but which have by the interposition of embankments been cut off from their natural watershed. By a series of cuts and works, which have been described elsewhere, the whole of the intercepted drainage is brought to bear upon an excavated channel, which commences at a point above the Ginnowli bridge, and from thence is carried on a straight line to the valley of the East Kalli Nuddi.

The necessity for connecting the low lands in this neighbourhood with the river above mentioned, and the convenience to the works of combining with the channel excavated for the purpose, an escape from the canal, led to the erection of the Ginnowli Escape head. During the dry season the channel is always available for canal regulating purposes; during the rains an increased and regular supply from the canal might maintain a flow of water down the cut, which would be very advantageous for the purposes of scour, and for ridding the channel of impediments.

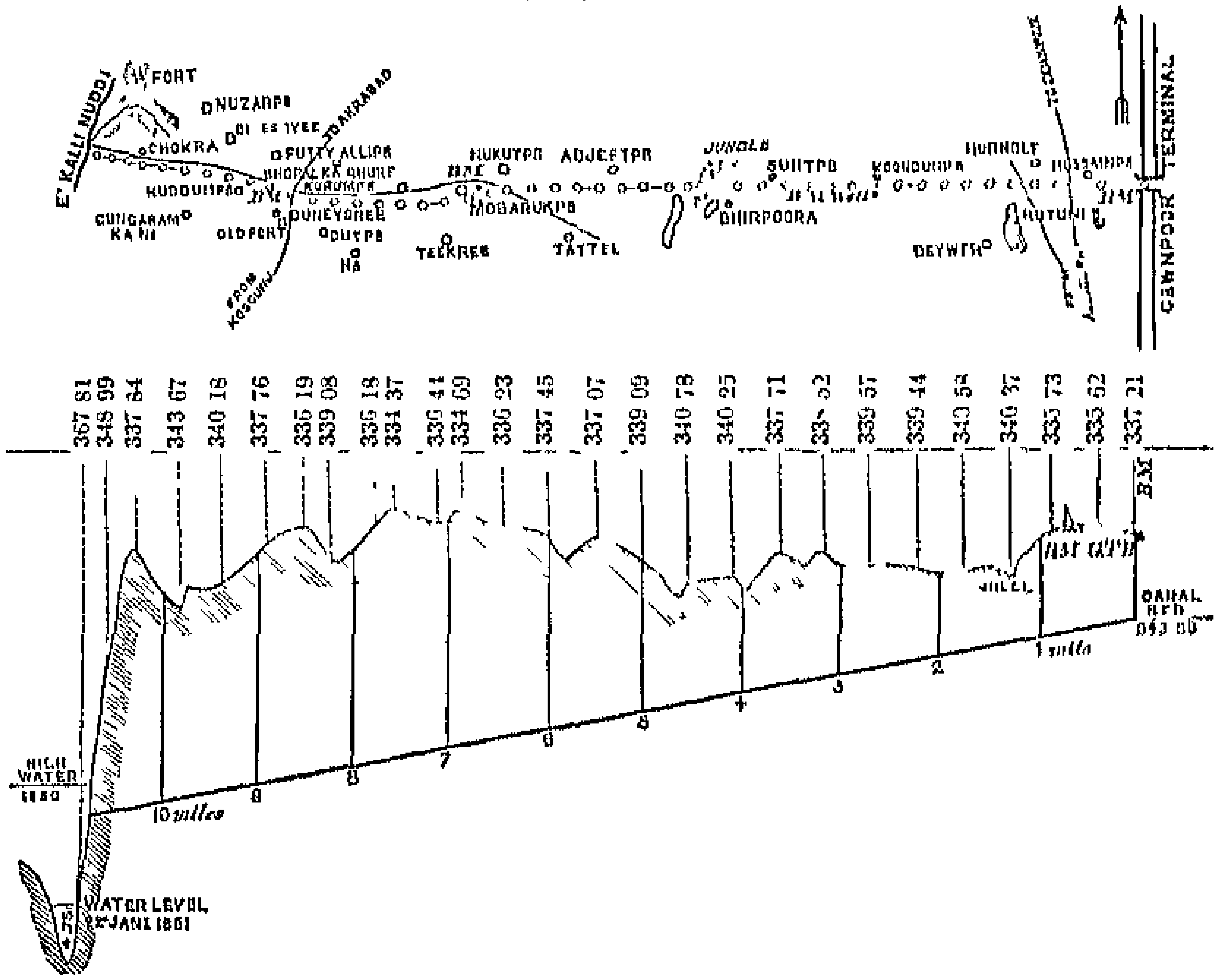
The channel here, as in the case of all those that have been excavated for the purposes of escape, is dependent for perfect efficiency on the wear and tear of the current. Here, as in the cases before described, the bed will be regulated from the escape head, as far as the leading bridge over which the *rajbuha* superpassage is carried: beyond that point, although the building of the necessary works is contemplated, it will not take place until the retrogression of levels caused by excess of slope

shows the absolute expediency of carrying them into execution.

The disposition of the works, and the particular points regarding slopes will be understood from the following diagram:—

Diagram 98.

GINNOWLI ESCAPE.



Length of channel from the canal to the East Kalli Nuddi		10 miles 4,652 feet.
Total fall from the bed of canal to bed of East Kalli Nuddi		28·67 feet.
Tail slope of escape head	1·00	
Slope on 11 miles at 1·5 feet per mile	16·50	
		17·50 ,,
Balance, superfluous slope		11·17 ,,

which will be disposed of in two masonry descents of $5\frac{1}{2}$ feet in depth each, the leading one, as in other cases, being that appropriated to the rajbuha superpassage.

A bridge for the passage of the Grand Trunk Road, crosses the escape channel at a distance of 3,724 feet from the head; a waterway of 30 feet clear has been given to this bridge, as the amount of water collected for the country drainage will be considerable. This amount of waterway might, in my opinion, be given to all the bridges on this escape channel.

The channel has been excavated on the same economical plan as that usually adopted; its width is only 10 feet, just sufficient to give a free and open passage for a current; which immediately after the canal supply was admitted might be passed down with the sole object of extending its dimensions, and preparing it for the large bodies of water which the rainy season would bring to bear upon it. The soil, through which this channel has been excavated, is of a more tenacious character than that met with in the upper districts of the canal, and it will consequently, I fear, offer more opposition to the effects of a current of running water in increasing its dimensions, than may be convenient; should this be the case, it will be advisable to aid the operations of the current by further excavations, as the early insurance of this line as an efficient escape is an object of undoubted importance to the country in its vicinity.

The proportions of material used in the cement were:—

5-6ths kunkur lime.
1-6th bujree.

The quantity of material used, and the rates of the work executed were as follow:—

	Bricks, 3 inch.	Block Kunkur.	Kunkur Lime.	Bujree.
Masonry .	85,200	2,270 cubic ft.	5,800 maunds.	1,136 maunds.

	RS.	A.	P.	
Masonry of all sorts . .	14	14	7	per 100 cubic feet.
Plastering	2	11	3	per 100 superficial feet.

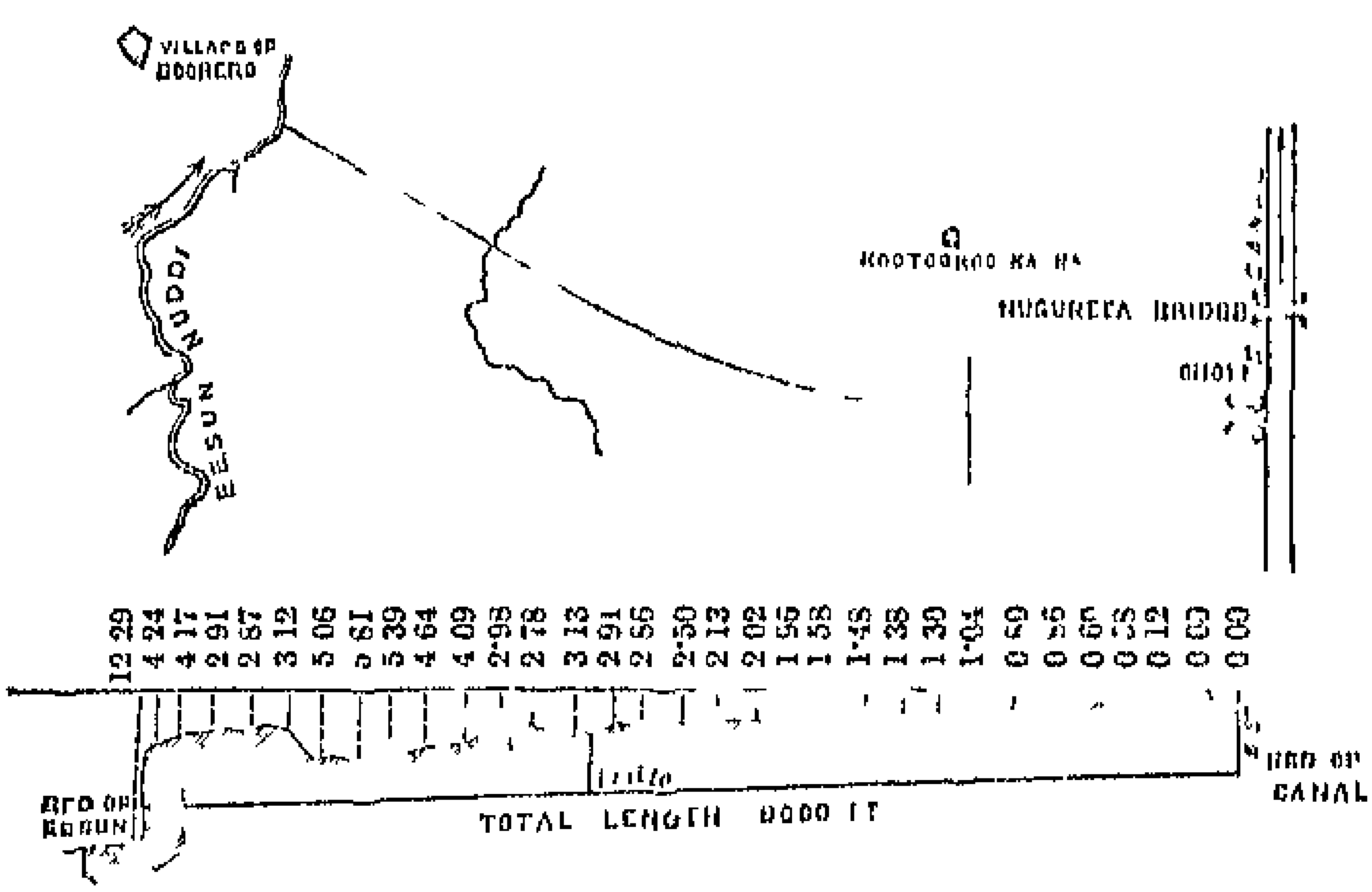
The Ginnowli Escape was begun and completed under the superintendence of Lieutenant Hodgson of the Bengal Engineers, at a cost of Co.'s Rs. 2,213-5-9.

No. 2.—Nugureea Escape.

Immediately above and attached to the Nugureea Bridge, which is situated 40 miles below Ginnowli, a second work for the purpose of regulating supply has been constructed under the above name. At this point the relative levels of the canal bed and of the Hindo River, made it necessary to turn our attention to the Eesun, which forms the left boundary of the tract of country upon which the line of the canal is carried.

Diagram 99.

NUGUREEA ESCAPE



Length of channel from the canal to the Eesun River		9,000 feet	
Total fall from bed of canal to bed of Eesun .		5·42	,,
Tail slope at escape-head . . .	1·00		
Slope at 1·5 feet per mile . . .	2·55		
		3·55	,,
Balance, superfluous slope .		1·87	,,

The River Eesun has at the point of its course on which the Nugureea Escape is directed, passed through 36 miles, on the whole of which it has been close to and in parallelism with the canal. The relative levels of the two channels, and the disposition of the works connected with escape, will be understood by the above diagram, the head being situated on the left bank of the canal.

It is doubtful whether it may be necessary to build permanent works on this line for the protection of the bed slopes, as during floods the high water in the Eesun will stand well back in the escape channel; the super-passage for the left main rajbuha, however, must as usual cross the escape, and it will be equally necessary for the convenience of the agricultural community to build a bridge. The same plan, therefore, will be adopted here, as has elsewhere been put in practice: viz., the super-passage channel will be connected with a bridge, the down-stream tail of which will be terminated by a fall sufficient to overcome the excess of slope, and to adapt the channel to the passage of water during the dry weather, without the inconvenience of wear and tear. I have, when describing the Cawnpoor terminal line, pointed out that the additional supply of water which the Nugureea Escape gives to the Eesun, will make an increase of waterway to a bridge built over the river near the town of Mynpoori very desirable; the bridge itself, which is on the high military road between Mynpoori and Agra, has for the last 20 years been in a state requiring repair and modification, and the improvement to its approaches, which will necessarily take place under the alterations which I have recommended, will add greatly to the facilities of cross communication. The site of the bridge in question is 16 miles below the junction of the Nugureea Escape, and it is situated in a valley of considerable width, and of great beauty from the verdure which attaches itself to all this line of river.

The Nugureea Escape head has five sluices of 6 feet in width each, with an excavated channel equal to 30 feet in width. The design is similar in all respects, excepting extent of waterway, and in not being connected with the bridge by masonry work, to the Moonda Khera and Kasimpoor Escape heads.

The proportions of material used in the cement are:—

2 parts kunkur lime.
1 part bujree.

The rates at which the work was executed are:—

	RS.	A.	P.	
Masonry of all sorts . .	15	12	7	per 100 cubic feet.
Plastering	2	11	6	per 100 superficial feet.

The building was begun and completed under the superintendence of Lieutenant Hodgson, at a cost of Co.'s Rs. 3,340-5-11.

No. 3.—The Tireea Escape.

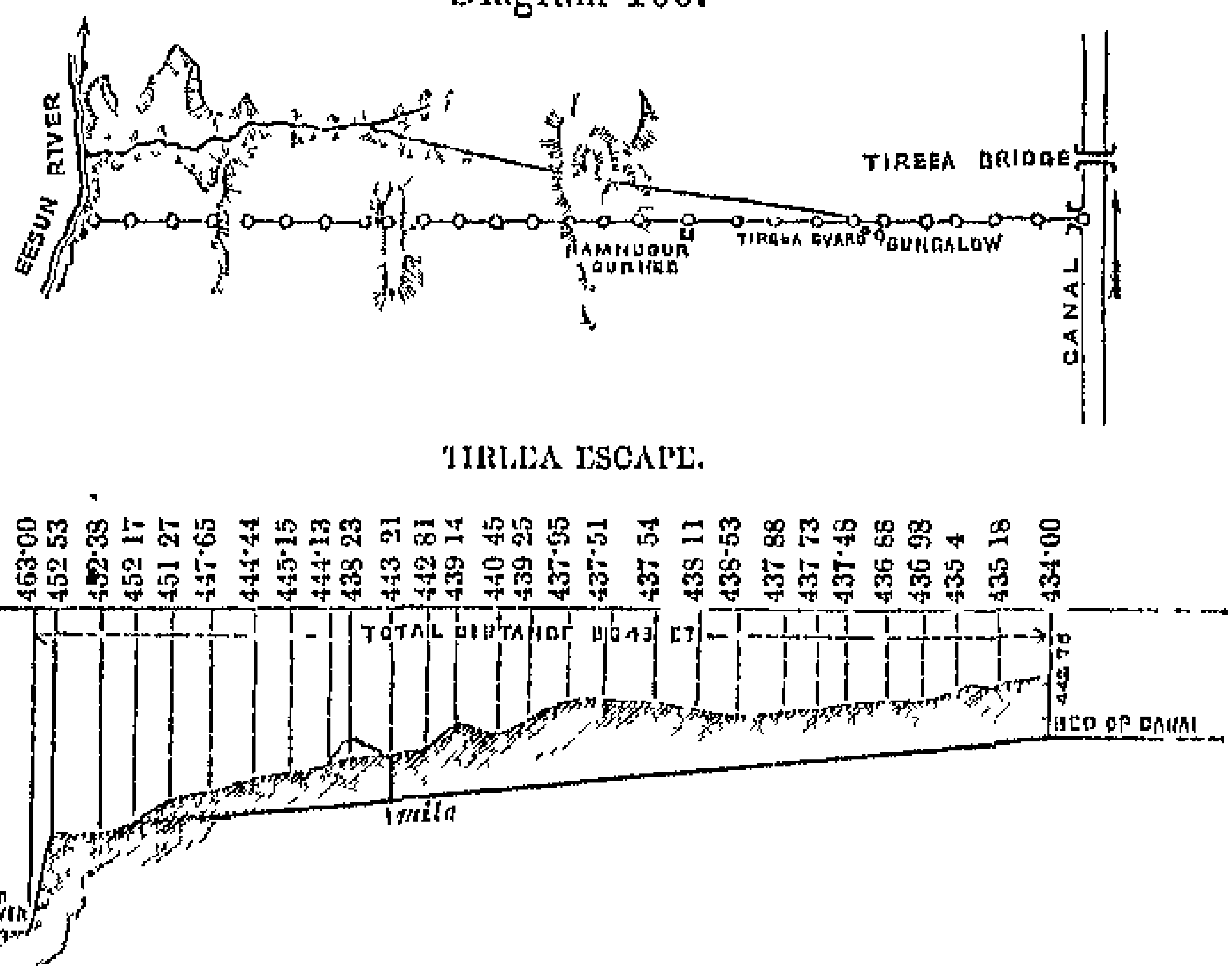
Here, again, from the insufficiency of the channel of the Rinde River to receive additional water, the canal escape has been turned to the Eesun. It will be observed, by reference to the map, that at a point between the 82nd and 83rd mile, and from the village of Daoodpoora, which stands on the most elevated ground between the Rinde and the Eesun, lines of drainage flow off towards both rivers, the larger one on the left of the canal, which I have elsewhere described as the Hussunpoor Nulla, being in the lower part of its course a ravine of great depth and size. This nulla appeared to be an appropriate site for escape water, and it has been used as such for the drainage of the lands lying above it. It was advisable, however, from the amount of drainage which we had passed into the Hussunpoor Nulla, to reserve it for that purpose solely; and with this view, an escape for regulating the canal

supply was fixed at a point four miles lower down, where the Eesun is in closer proximity with the canal, and where the channel of escape will be maintained for its own legitimate purposes.

The Tireea Escape, therefore, is situated at the 87th mile, its extent of waterway and design being the same as that at Nugureea.

The disposition of slopes will be understood by the following diagram:—

Diagram 100.



Length of channel from canal to Eesun River . .		8,043 feet.	
Total fall from bed of canal to bed of river . .		20·24	„
Tail slope at escape head	1·00		
Slope at 1·5 per mile	2·28		
		3·28	„
Balance, superfluous slope		16·96	„

As before described, this superfluous slope which will be gradually reduced by retrogression of level through the line of ravine, by which the escape reaches the river, will be fitted with masonry works hereafter; three descents

each of 6 feet in perpendicular drop will be ultimately required; of these one, to which the rajbuha passage will be adapted, will be built immediately; the remaining two will stand over until retrogression of levels has sufficiently acted upon the beds.

I may observe that this escape is the most effective one on the Cawnpoor terminal line; and as such, its centrical situation is fortunate.

The proportions of ingredients in the cement are about—

1 part kunkur lime.
1 part bujree.

The total quantity of material used, and the rates of the excavation and work in general, are shown by the following table:—

Bricks, 3 inch.	Bricks, 2¼ inch.	Block Kunkur	Kunkur Lime.	Bujree.
38,608	3,625	Cubic feet. 11,970	Maunds 5,503	Maunds 1,291

	RS.	A.	P.	
Masonry of all sorts . .	15	0	1	per 100 cubic feet.
Plastering	2	11	0	per 100 superficial feet.

The building was begun and completed by Lieutenant Hodgson at a cost of Co.'s Rs. 2,792-10-7.

No. 4.—KUKWAN ESCAPE.

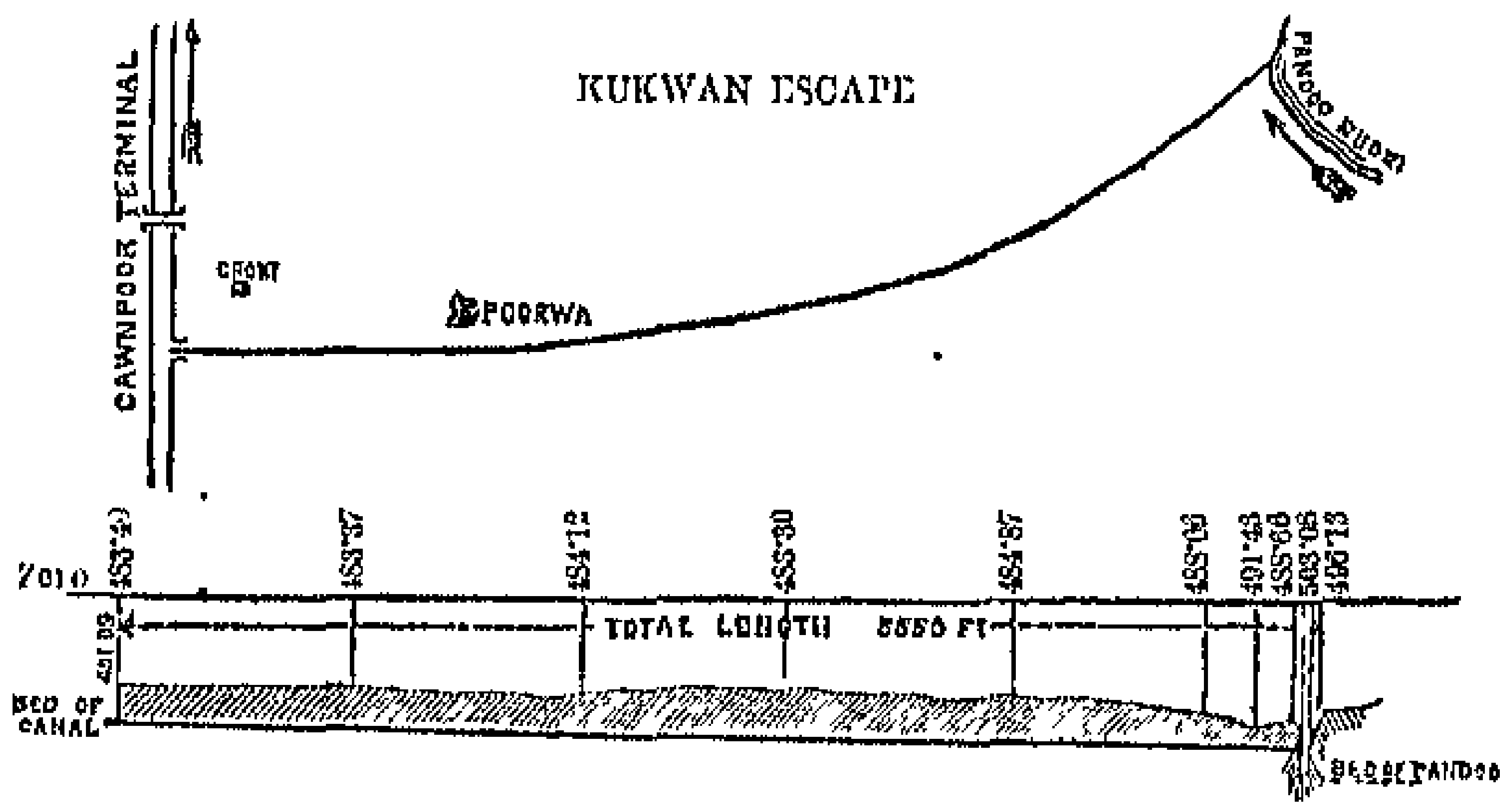
This work is situated at the 135th mile, or 12 miles below that at Tiroea: the channel is directed to the Pandoo River; the head, therefore, is on the right bank of the canal.

The size of the escape head is the same as that at Nugureea and Tiroea, viz., five openings of 6 feet each, and the building itself, with the excavated channel, is on

the same design; its situation, however, from the intervention of a high mound on which the first-class choki is built, is further removed from the bridge; and although, had time been given, I would have connected the two works by a line of ghat, such has not been done, and the escape itself, therefore, stands as an isolated and unconnected building.

The following diagram will exhibit in detail the disposition of slopes as connected with the canal and Pandoo on the Kukwan Escape.

Diagram 101.



Length of channel from the canal to Pandoo River .		5,550 feet
Total fall from bed of canal to bed of river . . .		11·99 „
Tail slope of escape head	1·00	
Slope at 1·5 foot per mile	1·57	
		2·57 „
Balance, superfluous slope		9·42 „

Even with this considerable difference of bed level between the canal and the river, we are entirely precluded from using this escape at periods of maximum high water in the Pandoo when floods to a great extent are running in that river: this high-water-mark stands on a level 2·43 feet *above* the bed of the canal; the Kukwan Escape, therefore, is literally only of use as a regulator during

dry weather, or moderate floods; at other periods it is scaled. I would, nevertheless, dispose of the surplus fall above noted, in the usual manner, especially with regard to the rajbuha super-passage bridge, to which I would give a tail descent of 6 feet, leaving the remaining slope to be determined by natural retrogression of bed levels: it is possible that there may be no necessity for the construction of further permanent works for the relief of the remaining 3·42 feet, to which the current will, in all probability, adapt itself.

The Pandoo River, in this part of its course, has all the objections that the Rinde had, and which in the case of the three escapes above described, led to my preferring the Eesun as a receptacle for our waste water. Having already thrown so much water into the channel of the Eesun, however, I was not inclined to load it with a further supply; and as the Pandoo was more conveniently situated with regard to the works, at the particular distance at which an escape had to be built, I preferred taking advantage of its channel, even under the obstacles which have been above explained, to pouring an additional volume during flood season into the Eesun. The Eesun, which runs at a distance of six miles from the canal on the line between Rouns and Kukwan, is, however, admirably adapted for escape water; its capacity of channel is great, and the channel itself runs through an extensive and deeply depressed valley: should, therefore, the Dubowli Escape head, which constitutes the leading work of the terminal buildings, and is provided with an escape equal to 36 feet in width in addition to the Dubowli rajbuha, whose head is 10 feet in width, be *insufficient to relieve the canal channel from flood-water* which is prevented from escaping at Kukwan, the remedy is open, in an additional line which may be carried to the Eesun from the canal, either at the Ootha Bridge, or (for

the advantages of supervision attendant upon the main post) from that at Kukwan: in the latter case the channel to the Eesun would be not less than eight miles in length, and the protective works would be proportionately more extensive. I do not think that such a work will be necessary; but if it is so, the remedy will be complete.

The proportions of ingredients used in the cement are:—

3-5ths kunkur lime.
2-5ths bujree.

The total quantity of material used, and the rates at which the several kinds of work were executed, are shown in the following table:—

	Bricks (3 inch).	Block Kunkur.	Kunkur Lime.	Bujree.
		Cubic feet.	Maunds.	Maunds.
Masonry . .	120,868	3,127	7,626	5,598

	RS.	A.	P.	
Masonry of all sorts . .	14	5	8	per 100 cubic feet.
Plastering	3	2	8	per 100 superficial feet.

The work was begun and completed by Lieutenant Hodgson, at a cost of Co.'s Rs. 3,214-2-10.

On the Cawnpoor terminal line, the power of regulating the canal supply during the dry weather is, I think, by means of the above escapes, in every way efficient. During the rains, however, this will be greatly aided by the rajbuha heads which are in almost all cases appendages to bridges. The disadvantage under which the Kukwan Escape labours, will only be felt during extraordinary floods: and as I have before said in such cases, the outlets at Dubowli, which equal in the aggregate 46 feet in width of waterway, will, it is to be hoped, do all the duty that is required from them.

C. *The Escapes on the Etawah Terminal Line.*

As in the case of the sister branch to Cawnpoor, the works under this section include all the outlets for regulating the canal supply lying between the head at Nanoon, and the terminal escape, which, as an integral portion of the works attached to the lockage into the Jumna River, is described under the head of the terminal works. The escape in question is situated at the 170th mile, and is similar in design, as it is adapted to similar purposes, with that at Dubowli.

The Etawah terminal line or branch, which runs to the Jumna, is bounded on one side by the Rinde, on the other by the Seyngoor River; between these two lines of drainage it continues uninterruptedly for 145 miles of its course, and in this respect it labours under the same disadvantages as the Cawnpoor branch, in so far that the Rinde in the early part of its course is as inapplicable to provide the means of escape for surplus water as I have before described it to be. The Seyngoor River, which runs on the right border of the strip of land through which the canal passes, although as deficient in capabilities for the especial purpose required in the early part of its progress, from its rise in the neighbourhood of Kool, proceeds on a more rapid slope than the Rinde, and, therefore, becomes at an earlier period better adapted for our purposes. At the 50th mile, the capacity of the Seyngoor and its relative levels with the canal bed, render it available as a receptacle for waste water; whereas it will be recollected that the Rinde at the 87th mile of its course was considered as incapable of being converted to a similar purpose. Below the points above-mentioned, both the Rinde and the Seyngoor gradually increase both in width and depth, and would admit of any additional supply that could possibly be turned off from the canal.

In determining the positions for escapes, I have been guided by the rules which were originally laid down, modified to a certain extent by local causes, and in the present case by the peculiar disposition of the lines of irrigation, which from Nanoon to the 100th mile, are confined almost entirely to the right bank, and to six leading lines of rajbuha, which cross the valley of the Seyngoor on their way to the Hatrass line of irrigation. These main lines of rajbuha will in themselves act largely as escapes for surplus water, and will, in all probability, without the aid of the regulating escape head, perform all that especial duty. Within the leading 30 miles of the course of the Etawah terminal line, there are no less than three out of the six main rajbuhas above alluded to: I have consequently (looking upon these as main lines of irrigation offering sufficient means for regulating supply) placed the escapes at the following points:—

No. 1. Gihror Escape, 57th mile.
No. 2. Mulhosi Escape, 103rd mile.
No. 3. Roora Escape, 143rd mile.

The escape at the head of the terminal works, and which, as I have before said, is included in the description of those works, is situated at the 170th mile.

No. 1.—Gihror Escape.

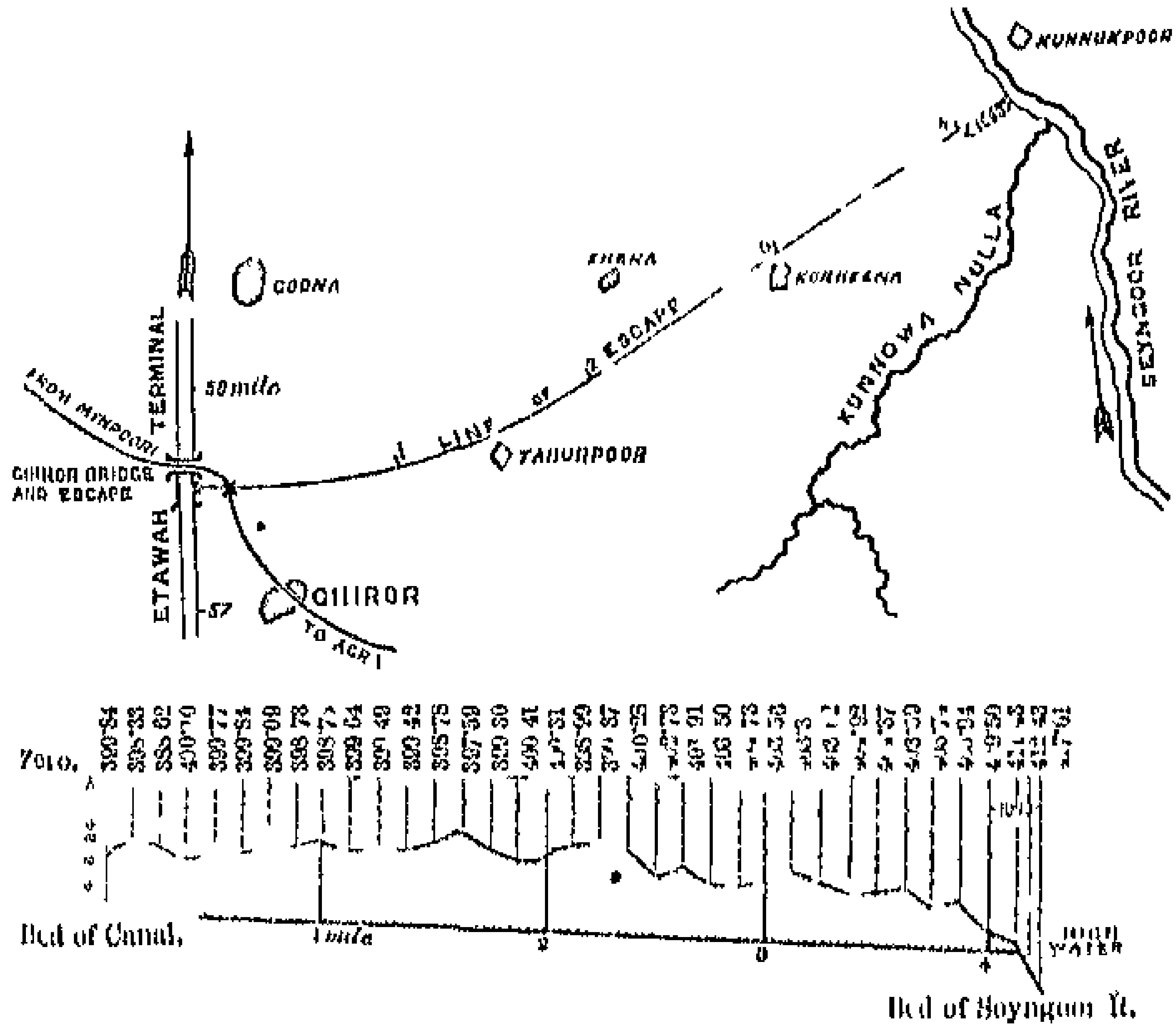
The head of this work is situated at the 57th mile, in connection with the bridge on the high road between Mynpoori and Agra: it lies on the right bank, and is joined to the Seyngoor River by an excavated channel. The width of the sluice waterway is equal to 30 feet, in five openings of 6 feet in width each: its design is similar in all respects to those which have been before described, and it is attached to the bridge by ghats in the usual ogee form. The works at Gihror may be considered as an

ornamental appendage to the high road on its passage across the Ganges Canal at that particular point.

The disposition of the works, in regard to slope of bed, and to its relative position to the Seyngoor River, will be understood by the following diagram:—

Diagram 102.

CHHOR ESCAPE.



Total length of channel from canal to Seyngoor River		4 miles 1,090 feet.
Total fall from the bed of the canal to the bed of the Seyngoor River		10·17 feet.
Tail slope at escape-head	1·000	
Slope on 4 miles 1,090 ft. at 1·5 ft. per mile	6·309	
		7·309 „
Balance, superfluous slope		3·861 „

This disposable slope might be arranged in a fall at the rajbuha super-passage bridge, as has been done in

other cases, so as to admit of retrogression of levels in the line of channel between it and the Seyngoor River, without fear of accident to the bridge. Here, however, we have a hard, tenacious soil, which probably would obviate the necessity of any protection to the works, even in the shape of the fall above proposed; such an arrangement would, nevertheless, place the works in perfect safety. In high floods in the Seyngoor, the water rises to a depth of between 6 and 7 feet; on these occasions there would be back-water in the escape channel, up to the rajbuha super-passage bridge-floorings.

The escape channel has been excavated on a rectangular width of 25 feet, with slopes equal to the depth, the slope of bed being equal to 1½ foot per mile: this, it will be understood, from what has been said before, is a mere economical arrangement, the true disposition of permanent slope being formed (*vide* Rule 5) on the calculations above figured.

Kunkur has been largely used in the works at Gihror as a building material, and in the difficulty which has attended on brick-making, has been of great service in expediting the completion of the work.

The ingredient used in the cement is pure kunkur lime. The total quantity of masonry, and the rates of the work, are:—22,676·2 cubic feet, at an average of Rs. 12-13-10 per 100 cubic feet.

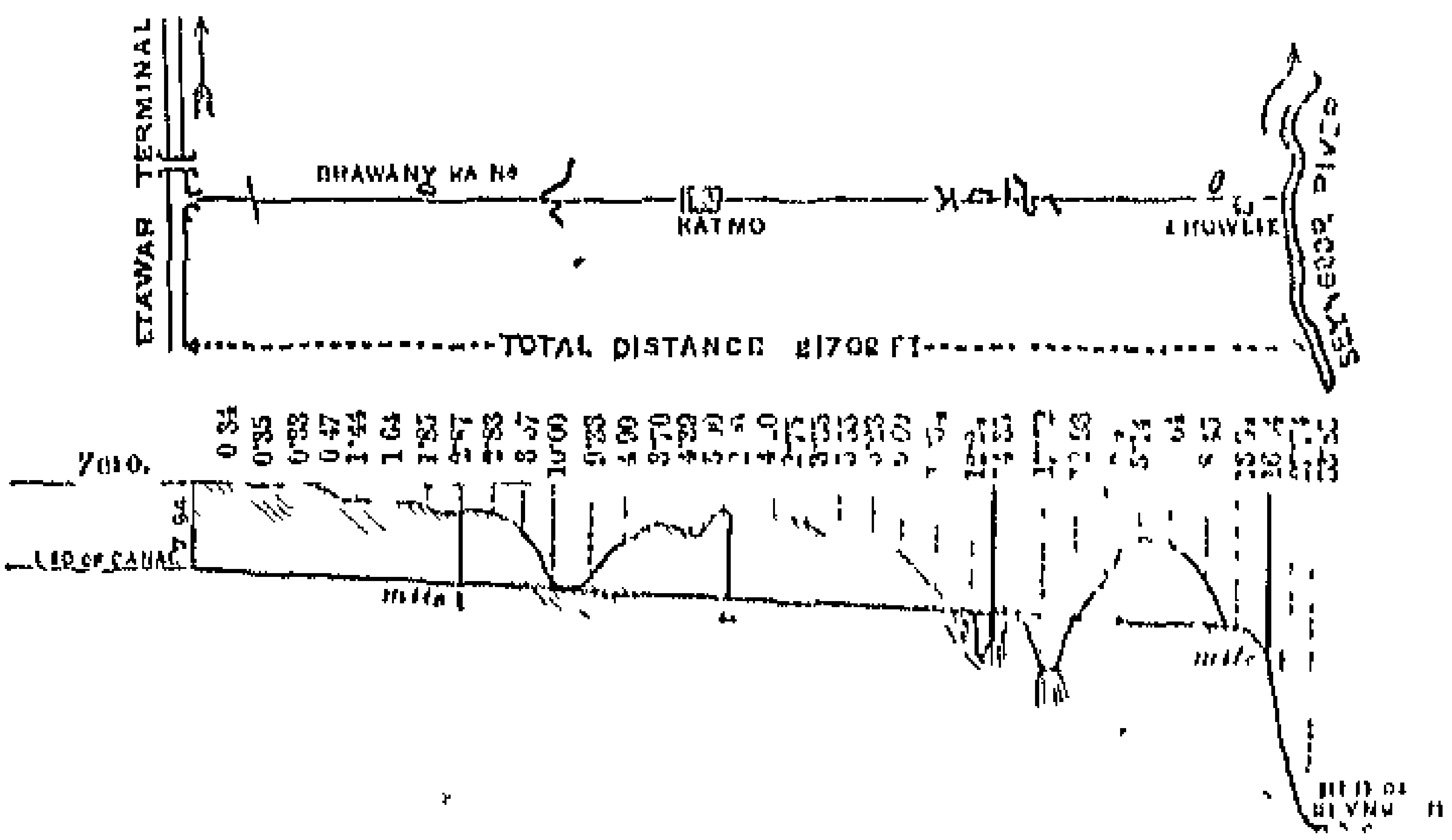
The Gihror Escape was begun and completed by Lieutenant Whiting, of the Engineers, who, as executive officer of the Etawah terminal line, superintended its construction, and looked after the progress in all its details. The total cost on this work was, exclusive of regulating apparatus, which will be fixed hereafter, Co.'s Rs. 2,917-3-2.

No. 2.—Mulhosi Escape.

This work, which is situated at the 103rd mile, at a point 46 miles below that of Gihror, is in every respect similar to it. In detail of design, and with reference to the bridge works at Mulhosi, it is identical with that at Gihror; it provides an escape equal to 30 feet in width in five sluices of 6 feet each, and throws its waste water into the Seyngoor River.

The disposition of the works in connection with the canal and the Seyngoor River will be understood from the following diagram:—

Diagram 108.
MULHOSI ESCAPE.



Length of channel from the canal to the Seyngoor River		4 miles 582 ft.
Total fall from the bed of the canal to the bed of the Seyngoor River		25·89 feet.
Tail slope at escape-head	1·00	
Slope at 4 miles 582 ft. at 1·5 ft. per mile	6·16	
		7·16 „
Balance, superfluous slope		18·73 „

To secure this line of channel on a permanent bed, three descents of masonry, with a fall of 6 feet each, will be

necessary, the leading one as usual being connected with a rajbuha super-passage. This, however, may be doubtful, as the channel of No. 6 main aqueduct rajbuha, directed upon the Hatrass line of irrigation, takes its departure from the Mulhosi Bridge—from the very work, in fact, of which the Mulhosi Escape head forms a component part.

The proposed line of escape channel enters the Seyngoor close under the village of Chouri, and in its passage intersects a good deal of irregular ground and cross drainage, which ought, in my opinion, to be passed without any attempt at taking advantage of the facilities which they apparently offer for reducing the length of the excavated channel. The first of these lines of cross drainage occurs at 1½ mile from the canal on the approach of the escape channel to the village of Kutmoo; it is a wide hollow, with its bed level with that of the canal, and is connected with the Seyngoor, to which it passes in the tortuous course that usually characterizes all nullas of this sort. The second lies within a distance of a mile from the Seyngoor, and between the road from Puhpoond and Etawah and that river. At this point the direct course of the escape traverses a whole series of twists of a line of nulla, the beds of which lie considerably below the level of the canal bed at Mulhosi.

There are very great advantages in maintaining an escape channel on a straight line, so that there may be as little impediment as possible to the free flow of the escape water, any interruption to which most materially depreciates the value of the work. I would, therefore—captivating as the Kutmoo, or that nulla lying within 1½ mile of the canal, may be, both in proximity and in capacity of channel—pass it entirely, keeping the canal escape in a direct line of bearing upon the Seyngoor River. At the point of intersection with the hollows to which I refer, I would throw embankments over the

nullas on the left of the escape channel only, so that the nulla water which arrives at that point may be forced to desert its natural course, and take to the artificial line of our escape.

The section upon which the channel will be excavated is the same as that at Gihror: viz., rectangular on a width of 25 feet, with slopes equal to the depth of digging; the bed slope equal to 1·5 foot in a mile. This work is not yet begun.

No. 3.—The Roora Escape.

This work is situated at the 143rd mile; it throws its water into the Rinde River, from which it is separated by *a distance of 17,200 feet; and the channel is, as in the* case of the Gimnowli Escape on the Cawnpoor terminal line, for the double purpose of relieving the country which lies on the left of the canal from intersected drainage, and for giving relief to the canal channel by disposing of its superfluous water.

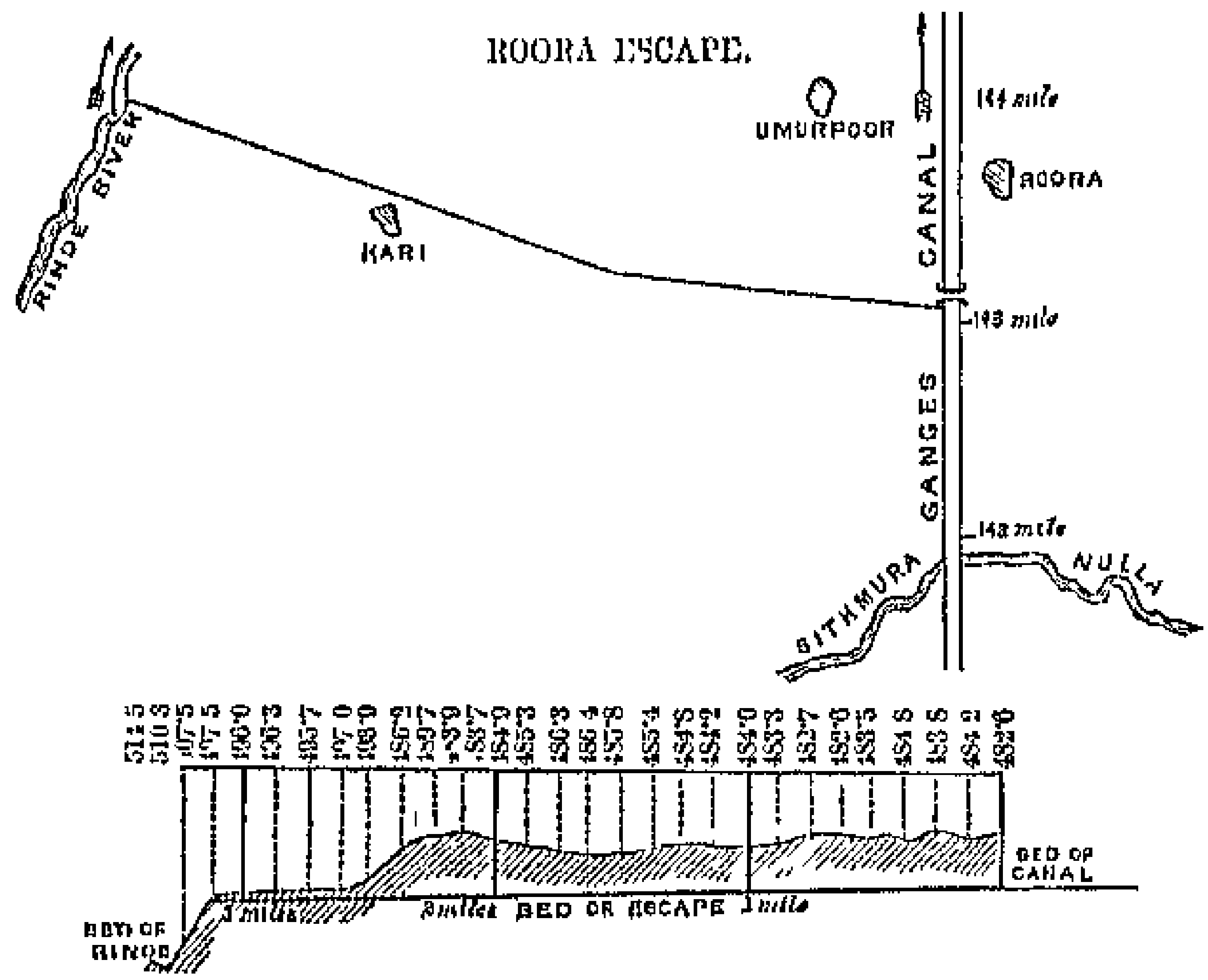
The Roora Escape leaves the canal above the villages *of Roora and Tugaon, at which point the alignment* takes an abrupt turn to the right, deserting its parallelism with the Rinde, and turning the heads of the Noon River. The canal where the escape leaves it has a rectangular width of 18 feet, with slopes equal to depth.

The head of the escape is provided with 3 sluices of 6 feet each, giving a full waterway of 18 feet. The dis*position of the slopes of the channel between it and the* Rinde is shown in the following diagram.

As it is doubtful whether a rajbaha channel will cross this line, it may be convenient, with reference to the duties that it is called upon to perform, to leave the bed on its excavated slope, without hurrying to completion works for overcoming the superfluous slope. I would therefore recommend that all necessary material should be col-

lected for the purpose of building descents of masonry, to meet the retrogression of levels, should such appear to be working dangerously upon the tail of the escape;

Diagram 104.



Length of channel from the canal to the Rinde River		3 miles 1,520 ft.
Total fall from the bed of the canal to the bed of the Rinde River		22·16 feet.
Tail slope of escape head	1·00	
Slope on 3 miles 1,520 ft. at 1·5 ft. per mile	4·93	
		5·93 „
Balance, superfluous slope		16·23 „

but I would postpone their construction until opportunity offers, or until there is a real necessity for them. The extensive line of country which this channel is intended to drain, and the advantage of extraordinary slope of bed in facilitating the escape of water, will, in all probability, make it desirable to obtain the greatest possible depth to this channel; in which case, I should be inclined to make the first descent immediately at the tail of the escape head, in the same way that has been done

Khori Kurmoo Escape on the Eastern Jumna Canal. This method gives extraordinary facilities for relieving the canal channel from water, and if the fall is built at a distance from the tail not exceeding 80 or 100 feet, there can be no danger to the escape head.

The width of the channel from the head to the Rindo River, is proposed to be 30 feet, with additional slopes equal to the depth. This width will provide capacity for carrying off the country flood-water, as well as that from the canal. For a description of the drainage connected with these works, Part II., and diagram 53 should be consulted.

At the time that I am writing, the works on the Etawah terminal line are not sufficiently advanced to bring them in contact with this part of the country: the presence of kunkur, however, which is abundant everywhere, will greatly facilitate the completion of any works that may be required. I may observe, in conclusion, that the Roora Escape will be connected with a bridge, and be built on the standard plan laid down for the guidance of executive officers.

The above building completes the works for regulating the supply of the Etawah terminal line: their position, it will be understood from what has been before said, has been determined in a great measure by that of the main rajbuhas connected with the Hatrass irrigation, all of which will be useful accessories in the way of regulating the water. In the case of the Roora Escape, the *position of the work is in some way connected with* country drainage. The arrangements, taken in the whole, will, I think, be sufficient for the required purposes.

The only work for regulating supply which lies below the Roora Escape, is that at the 170th mile, which as the up-stream terminus of the lock works into the Jumna, will be described in the chapter devoted to those works.

I may remark, however, that the rajbuhas leading towards the eastern tracts of the Ghatumpoor purgunna, which commence immediately below the Roora Escape, will ultimately afford their aid to the purposes of regulation.

The subordinate lines of canal, which have been described under the heads of the Futtigurh, Bolundshuhur, and Kool branches, as well as the main lines of rajbuha, are all fitted with works for regulating purposes: to these particular works there is no necessity to make any reference, as the execution of the branches has been postponed, and that of the rajbuhas was only commenced in May, 1853; nor would I offer any opinion as to the advisability of following the design which I have adopted for either the escape-heads or for completing their channels: the latter is distinctly an economical expedient, and may possibly require modification; at any rate, the advantages of practical observation on the works which have been already built on the main canal and its two terminal lines, and on the effects of the current depending upon their position and design, will, at a sufficiently early period, place my successor in a position to remedy any defects and to supply any deficiencies.

IV. *Falls or Descents to overcome superfluous Slope.*

In projecting the slopes of a canal bed, and after determining the amount of declivity of the country upon which the alignement is to be carried, it becomes necessary to dispose of the superfluous fall by artificial means, either by weirs or rapids constructed of piling and rubble work; or by buildings of a more permanent nature of stone or brick masonry. The longitudinal section, therefore, is laid out in a series of steps, the length of tread and the height of lift being determined by the profile of the country.

On the Ganges Canal channel, with the exception of the first two miles of its course extending from the Myapoor regulator to the Kunkhul bridge, where the bed consists of boulders and shingle, and to which a slope of 2 feet per mile has been given; and of the next three miles, extending to the Ranipoor works, which have a slope of 1½ foot per mile; the slopes in no case exceed 1·25 feet, and they vary from a maximum of 1·25 to a minimum of 1 foot per mile. At every three miles of its course, and in many cases at shorter intervals, the floorings of bridges act as retainers of the slope, so that were a retrogression of levels equal to the whole amount of the fall between two bridges to take place, the maximum declivity upon the flooring could not exceed 3·75 feet. The action of the current under such extreme circumstances would be still further opposed in all cases where the bridge floorings have been laid in in a light soil, by strong aprons of piling and rubble work, well clamped together in wooden frames, and protected by an upper sheeting of sleepers.

The canal bed, it will be understood from the above description, consists of a longitudinal series of open lines of earthen channel carried on slopes varying from 1·25 to 1 foot per mile, crossed at every three miles by masonry bars, and terminated at the extremity of each line by a sudden and abrupt change in the levels.

In any natural equalization of slope, arising from an absence of artificial regimen, the operation will be limited in the aggregate by the works built for overcoming the sudden change of levels; and in detail by the cross bars or floorings of bridges to which I have before adverted. The ill effects of retrogression of levels, therefore, are contracted within manageable limits, and it will be well to consider hereafter, when the erection of further bridges is proposed, that independently of the

value of additional cross-communication which every work of this sort must inevitably bestow on the country, its floorings will place a still further limit upon the evils of retrogression.

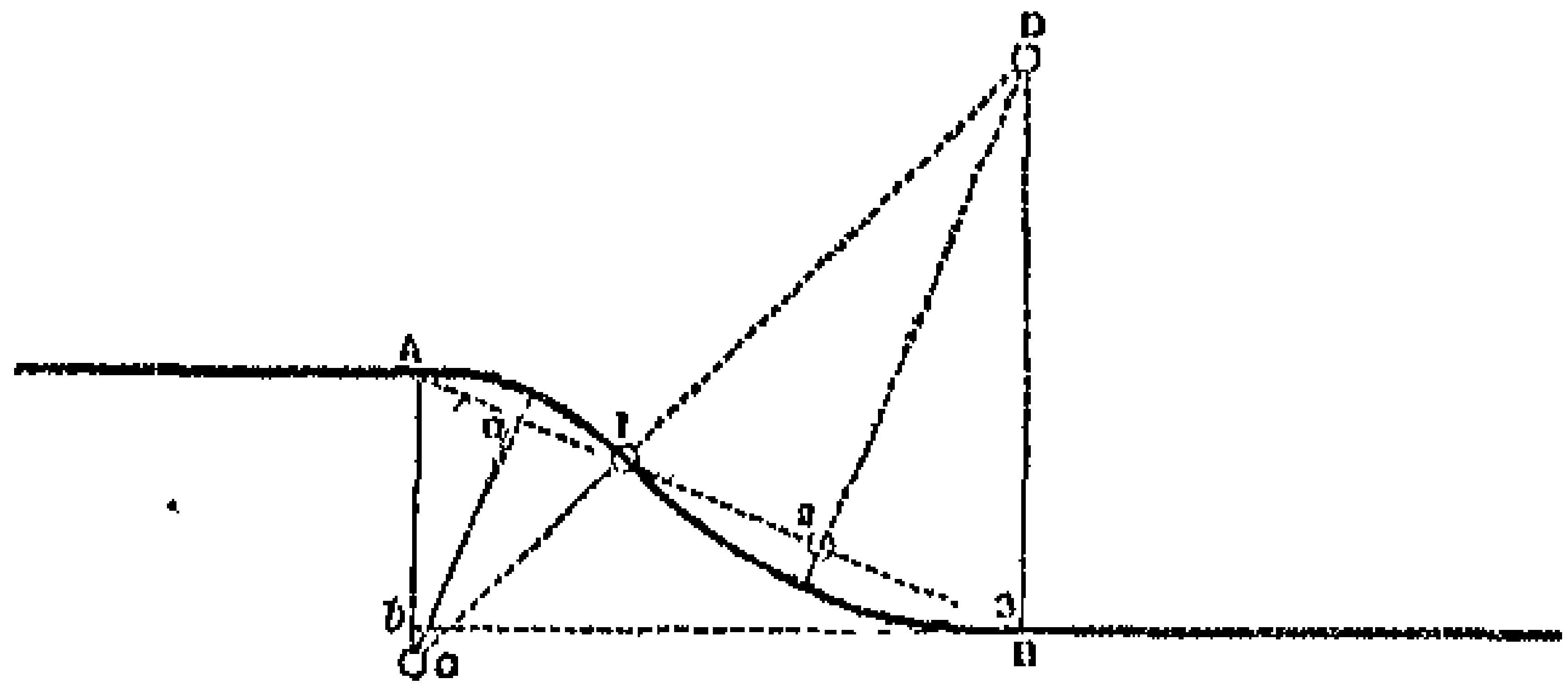
The design which I had (in the restoration of the Eastern Jumna Canal bed) successfully put into execution, appeared to me to have at least the merit of practical applicability to circumstances attendant on this sudden change from a high to a low level, as well as to the easy flow of the current in passing from one to the other. With the exception, therefore, of details in construction, consequent on the magnitude of the volume of water with which we had to deal on the Ganges Canal, the general design of the falls may be considered identical; it is, in fact, a well-protected bar or overfall of masonry, with its face in the form of an ogee curve for the water to glide over in its passage from the upper to the lower levels.

Without entering into mathematical demonstrations of the value of the particular curves which are supposed to be best adapted to the purpose (on which subject much learned dissertation has been expended by De Bossut in his work *Sur les Digues*, and by other French and Italian engineers), I have selected those which from observation of numerous ogees built upon the canals in these provinces, and more especially of those which now exist on the Eastern Jumna Canal works, have shown the most satisfactory practical results of their applicability. The curve in question is represented by the diagram on the following page.

Over curves of the above description, when the intermediate obstruction of piers is equal to 4 feet in width, water to a depth of 3¾ feet passes through waterways of 15 and 20 feet in width easily and quietly. I conclude, therefore, that with a depth of 5 feet, which is that

theoretically due to a maximum supply of water in the Ganges Canal, the waterways of the falls, which are 25 feet, with intermediate obstructions of 4 feet, will do their duty equally satisfactorily.

Diagram 105.



$b\,B = \frac{5}{2}\,A\,b$

$A\,1 = \frac{A\,B}{8}$

A C } Perpendicular
D B } to Flooring.

Bisect A 1, and from the point of bisection at *a* draw a perpendicular cutting the line A C at C.

Join C 1, prolonging the line until it cuts the line D B at D.

From the points C and D as centres draw the curves of the ogee.

I must here say a few words on the value of perpendicular descents, which have been so strongly advocated, and which nobody can more strongly advocate under certain circumstances than myself. Nature, in cases where retrogression of levels occurs in a rocky country, terminates this retrogression by a vertical fall. In a country where rock does not exist, she prevents this abrupt retrogression, or remedies it rather, by causing the river to run on extended twists, which by lengthening its course, and consequently reducing the amount of slope upon which it runs, puts a stop to the violent action of the current, and thereby to retrogression. It is true that, in the case first mentioned, the perpendicular descent may be qualified by a talus of rocky masses lying at its foot; and in the latter case, varieties of soil may effect the uniformity of current; but there is the great fact, that in rocky countries where the surface is divided

into extensive flats, lying at different elevations, and forming what are usually termed steppes, or sudden drops in the position of table-land, Nature pours her water perpendicularly over a precipice into a vast basin excavated for its reception, and in which the violent action and regurgitation caused by its fall, exhaust themselves. In the absence of rock the natural law is equally apparent; here the water by a gradual process gets rid of its perpendicular fall by a retrogression of levels, and by forming huge ravines, on a course regulated by the tenacity of soil with which it comes in contact, exhibits itself ultimately in an evenly flowing stream, running on a course more or less tortuous, depending on the amount of perpendicularity of level that it had to overcome.

As an exemplification of the first case, without going so far as America and the Canadas, the Rewa Falls, or those which deliver the water over the great step of the Vindhya range of Central India may be given. The Kuti Fall has a perpendicular height of upwards of 400 feet. The body of water, with the exception of that in the rainy season, is small; but during the monsoon the volume is *said to be tremendous*. *I have a vivid recol*lection of an account given to me of these falls, by my friend the late Colonel Edward Smith, of the Bengal Engineers, who paid them a visit during the rains on purpose to test the accuracy of their measurements.

Of the second case, the Jumna from its junction with the Ganges at Allahabad upwards, the Chumbul from its junction with the Jumna upwards, and the different inland rivers of the Northern Doab, of which so much has been written in these chapters, are all excellent examples. The operations of retrogression through high land, with all its detail of tortuosity and lateral drainage, is well exhibited in the regions where the rivers above mentioned join those to which they are tributary. In

the neighbourhood of Agra even, the Jumna flows through a labyrinth of impracticable ravines, equal in breadth to three miles; and the Chumbul, on the frontier separating the Gwalior from the British territories, runs through a belt of broken and raviny country, the width of which is not, I believe, less than six miles; the smaller rivers to which I have alluded, although with a volume of water of an extent comparatively trifling, are in the lower part of their courses attended by broken ground of a description similar to that on the larger rivers, and on an area that would be viewed with astonishment by those who overlook the causes and the length of time through which their effects have been in operation.

Although, however, it may have been convenient for the argument to view the action of water as above described under two separate heads, it must not be overlooked, that the whole question of retrogression, whether in rock, clay, or sand, is merely one of degree. That in both the cases which I have above quoted, time, and time only, is required to reduce them to the same category; and that the perpendicular fall which nature gives to her rocky obstructions is merely a prelude to its ultimate disintegration, and to its being worn away and shattered to pieces, in the same manner that sand or clay would have been, only at longer intervals of time.

Nature, in her adaptation of perpendicular descents to the volumes of water which pass over them, introduces all the necessary elements for this ultimate destruction: the cataract which by constant attrition wears away the rock on the upper levels, by its action in the abyss below undermines the rock itself; it is limited in its action by no artificial impediments, and it is hampered in its movements by no unnatural restrictions. It is entirely free, and it arranges its own works accordingly.

In an artificial fall constructed on the above principles,

we have the volume of water passing over a perpendicular descent, at the foot of which is a deep and spacious basin, capable of receiving the cataract in its downward descent, and sufficiently capacious to admit of the regurgitation and violence with which the water is agitated, being expended before it flows off and proceeds onwards. The building in the case of the Ganges Canal works must have been of brick masonry, that is to say, of small prisms of burnt clay (not exceeding one-eighth of a cubic foot in dimensions) cemented together by mortar, and therefore presenting innumerable seams to the action of the fluid. This building would have been a massive one, although hardly more so than that which has been actually constructed; it would have rested in almost every case in sand, and it would have been protected most securely from bed and side action of the current. It would, in fact, have been precisely in the same condition with regard to material and soil that the works are at present.

I must here beg the reader to refer to Plate XXI. of the Atlas, showing the Bahadoorabad Falls, which is a fair representation of the works of this description which have been built on the Ganges Canal: he must look to the general massiveness of the substructure, to the enormous thickness of the chamber-floorings and work in connection with them, and then bear in mind the fact, that a person standing on these floorings, during the time when a pile engine (with a rammer of 1,000lbs. weight in a drop of 20 feet) is at work within 10 feet distance of the sill of the ogee on the upper levels of the canal bed, feels distinctly the concussion of every blow, and of every descent of the rammer on the pile head. It appears to be unnecessary to speculate on the way in which the sensation is conveyed; it is sufficient for the purpose of my argument to be satisfied that it takes

place, and being so satisfied, to turn the reader's attention to the probable consequences of a concussion directly on the building itself arising from the perpendicular descent over a fall of 8 or 9 feet of a body of water equal in cubic content to 6,750 cubic feet, or in weight to 188·3 tons per second, falling without intermission, and in an unbroken and continuous volume.

We know that in natural cataracts neither the rock over which the water pours, nor the abyss into which it falls, are in the smallest degree constant; they are perpetually undergoing change, and periodically subject to catastrophes. The natural rock is a portion of the "firm, firm earth," rigid and immoveable, excepting by the action of the opposing cataract. The artificial fall is a collection of small pieces of burnt clay connected into one mass by the intervention of mortar; it is in no way connected with the soil in its neighbourhood; with it, it is in no ways homogeneous; the very circumstances under which it is constructed render the soil in its immediate contact inferior in density to that of the intact and virgin soil which has not been touched by the excavator; it is in the extreme sense seated in a crater, and in matter that has no sort of sympathy with it.

I have from the first considered this question of perpendicular fall, under every imaginable point of view that offered itself, and I am fully impressed with the conviction, that in dealing with large masses of water as we are proposing to do in the Ganges Canal works, under the circumstances of the soil and slope of the bed; under the nature of the material with which we are forced to construct our buildings; and under a continuous flow of water equal to that which I have noted above;—the *perpendicular fall would be inapplicable; it* would, in my opinion, be expensive and dangerous; and, further than this, I cannot imagine that floorings made of brick would

for any length of time be able to withstand the concussion, and the violent action of the water in the reservoir.

Although discussing a principle, I have used the expression "expense" in the foregoing paragraph. This item would in many of our falls have been one, attendant in an exorbitant degree on the adoption of the perpendicular and reservoir plan. The reservoir, to be efficient, must have been equal in depth to the height of the fall, or at least equal to one-half of it; its sides and floorings must have been built of the most massive proportions, and the work, supposing that brick is used, must have been most carefully executed. In cases such as the Puttri Falls, where the foundations were actually laid $21\frac{1}{2}$ feet below the surface of springs, and where I was obliged to sacrifice the reservoir at the foot of the drop at the lock chamber, in consequence of the extreme difficulties that we had to contend against,—the cost of perpendicular falls, with their necessarily attendant reservoirs, would have been enormous: the same remark would apply to the falls at Sulawur, Bhola, Dasna, and Simra, at all and each of which the foundations are laid on a level below that of the natural spring surface.

The conclusions that I have arrived at are these: First, that in rivers or canals where the slope of bed is small, and where back-water stands upon the foot of the falls, the water may be allowed to pass over a perpendicular face, the height of which is restricted within moderate limits with perfect impunity, even without the existence of tail reservoirs: the dams or annicuts in the Madras Presidency are examples of the success of perpendicular falls under the above circumstances. Secondly, that in rivers or canals on rapid slopes, where back-water is deficient, perpendicular falls, even on a moderate height, are inapplicable; and where the height or amount of fall is great, and where the volume of water

is large, that they are dangerous. I consider, moreover, that this applies to the main streams of the canals in these provinces, and more especially to the Ganges Canal. On the minor streams and branches (rajbuhas, for instance), where the slopes are moderate and the volume of water small, perpendicular falls might perhaps be substituted for the ogees now in use. I see no especial advantage, however, in the change; there is certainly none in economy, as the cost of reservoirs would absorb any saving that might be contemplated in reducing the length of the tail flank walls; these walls, too, are so frequently used as the support of arches for cross communication, that here again nothing would be saved. With regard to maintenance and repair, the effects of falling bodies of water upon the masonry of which our works are constructed, might be worthy of consideration.

I am not sure whether *noise* may be accepted as a serious and sober reason of objection; but if so, the perpendicular fall would most especially be open to it. In the Khadir there are four falls, each with a drop of 9 feet, situated within a length of 4½ miles; to imagine the roar that would be raised by the continuous descent of 188 tons of water over these perpendicular cataracts, is worthy of the consideration of those who disapprove of the ogees which I have constructed.'

I have proceeded to a greater length on the above subject than I had originally intended; but it is one that has given me much thought, and the views that I have adopted have only been decided on after mature deliberation. Fully appreciating as I do the advantages of studying nature in all her operations, I believe that I have, in rejecting the perpendicular descents for the main line and branches of the Ganges Canal works, shown in the clearest possible way the advantages that I have derived from this study.

The choice appeared to me to lie between an inclined plane and an ogee, of both of which we have examples on the Eastern Jumna Canal. My reason for rejecting the inclined plane was, that it would have required a greater length of chamber, with a greater surface exposed to attrition; and in all probability, a greater cubic content of masonry work: the objections were solely of an economical nature, and were quite independent of any peculiar preference.

The selection having been made of the ogee shape of overfall, the curves upon which it was to be described were determined as before noted, and as represented in diagram 105.

The falls themselves may be divided into three series:—

I. Falls with a drop of 9 feet.
II. Falls with a drop of 8 feet.
III. Falls with a drop of 5 feet.

I. *Falls with a Drop of 9 feet.*

Those under this item are confined to the Ganges Khadir; they are four in number, and come under the following designation:—

No. 1. Ranipoor, or Kay's Falls.
No. 2. Bahadoorabad, or Parker's Falls.
No. 3. Bahadoorabad, or Goodwyn's Falls.
No. 4. Puttri, or Login's Falls.

As No. 1 and No. 4 are connected with the super-passages, and form component parts of those works, they have been described in the chapter devoted to Super-passages.

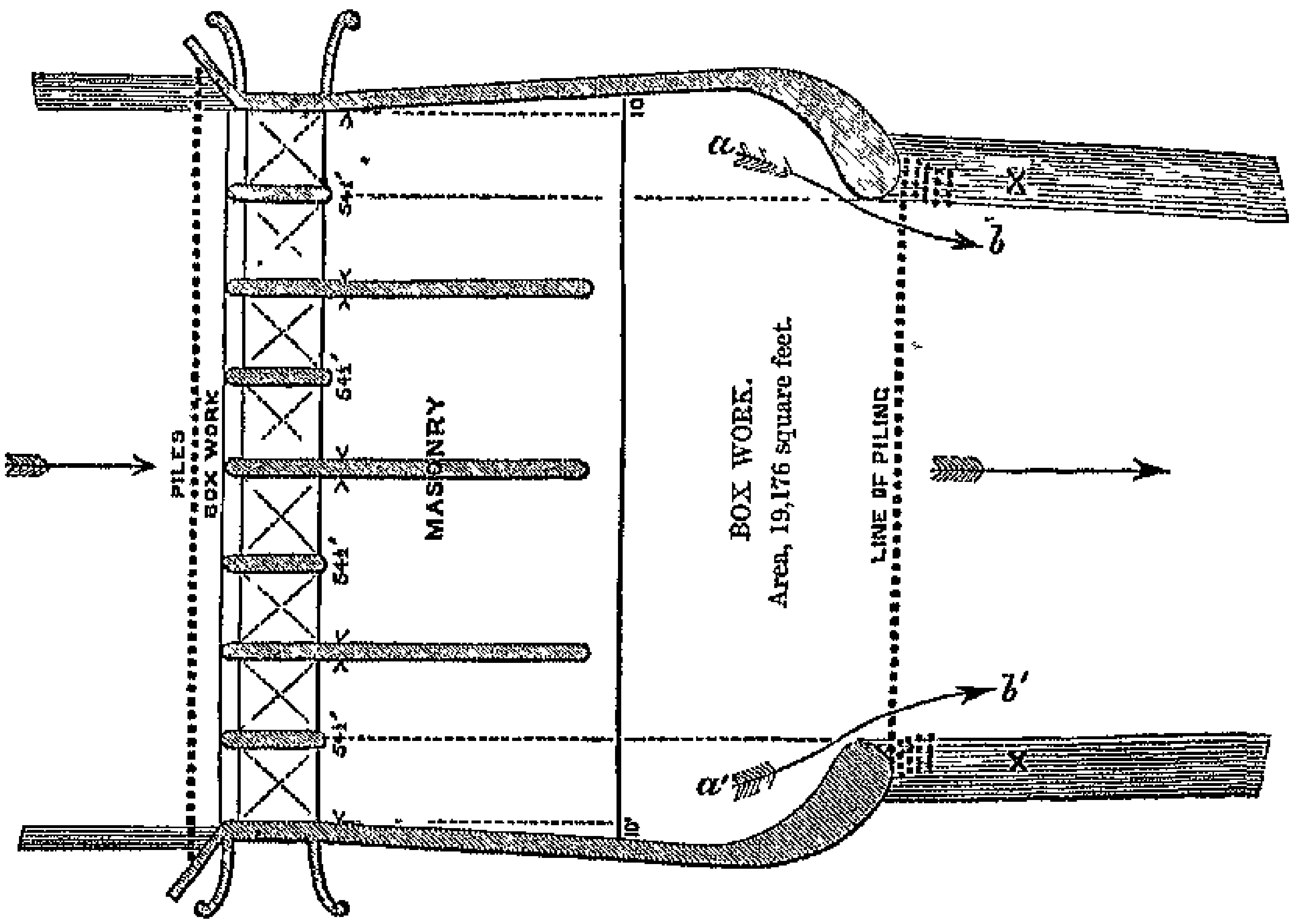
No. 2 fall consists of a bridge (of eight bays of 25 feet in width each), which crosses the canal on the upper levels; to the tail of this bridge the ogees are attached,

delivering the water into four chambers of 54½ feet each in width, every alternate bridge-pier being prolonged on its down-stream face, so as to divide the space which is occupied by the lower floorings into four compartments; in advance of these dividing walls, which are carried to a distance of 84 feet from the down-stream face of the bridge, there is an open space of masonry flooring, which is protected by an advanced area of box-work, or heavy material filled into boxes or crates, and covered with sleepers, so as to retain the material in position. Additional defences are given to these floorings by lines of sheet piling. The flanks of the chambers below the descent are protected by revetments, equal in height to the dividing walls. These flanks, instead of being in prolongation of the alignement of the bridge abutments, expand outwardly, gaining, on their arrival at the tail of the masonry platform, an excess of 20 feet in width. At a distance of 37½ feet from this point, the flanks make a slight curve inwards, terminating (on an imaginary line drawn in prolongation of the pier next to the abutment) in massive projecting jetties. Between, and on the flanks of these two jetties, lines of piles, and other protective arrangements are distributed, so as to secure the safe passage of the water over the floorings, and to admit of the current escaping from the works with as little tendency to danger as possible. The depth to which the curtain or upper foundation wall is carried is equal to 20 feet; that of the tail, with the flank revetments and jetties, is also 20 feet.

For the plan of this work I must refer to the Atlas, Plate XXI. The following outline in diagram, however, will show the general design; and its introduction here will enable me to describe the views by which I have been guided in laying out the side revetments, in protecting the flanks, and in endeavouring to secure a safe and easy

exit for the current after its passage over the masonry descents.

Diagram 106.



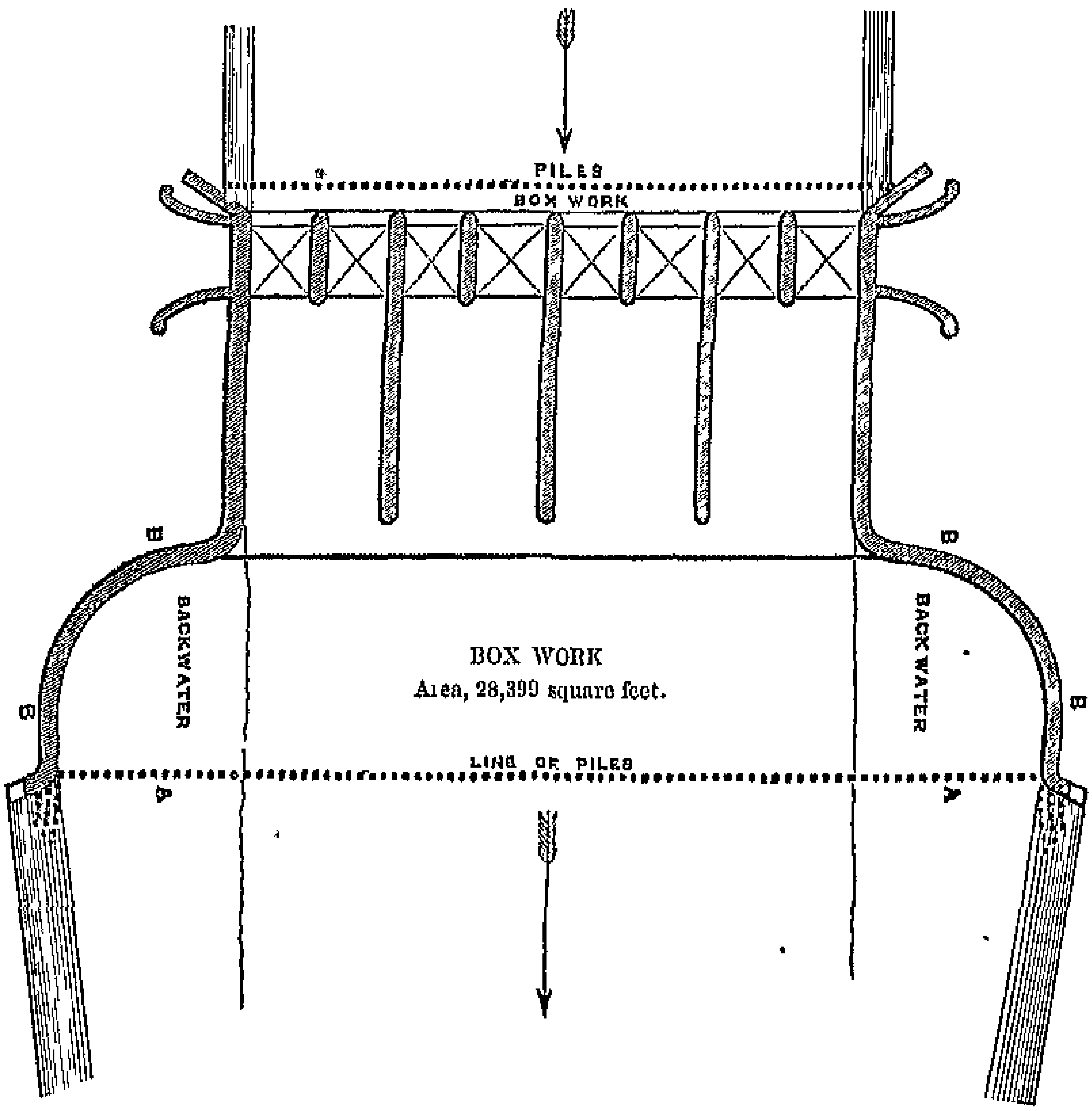
As the above is the plan upon which the whole of the falls on the Ganges Canal, with the exception of those at Belra (to be hereafter described), have been executed, I shall here give an outline of the works at Belra, so that, by putting it in juxtaposition with that shown in the above diagram, the explanation that I am about to offer may be easily comprehended.

Diagrams 106 and 107 represent two different plans of flank and tail arrangements; that in diagram 107 being the original design upon which one work only (viz., that at Belra) has been executed; that in diagram 106, being a modification of the other, and that on which the rest of the masonry falls have been completed.

The great objects in works of this sort are to secure a free and uninterrupted passage for the current on its

escape from the turmoil and agitation attendant on the *passage of the water over the falls; to relieve the current* from all provocation, irritation, and vexation, on its passage from the masonry to the earthen channel; and

Diagram 107.



finally, to use every precaution and expedient not only to direct the current upon the centre of the canal channel, but, if possible, to maintain it in that position on its forward movement.

The plans shown in the above diagrams may be described as "active" and "passive" examples of works designed for the purpose of obtaining the desiderata above

mentioned; diagram 106 (active) being so designed that the currents sweeping along the feet of the flank walls on the right and left, as shown by the arrows *a b*, *a′ b′*, shall, by impinging on the main body of water on its escape from the masonry building, give their artificial aid to retain the current in a centrical position, and at the same time afford protection to the slopes at × ×; diagram 107 (passive) leaving the desired objects to be attained by back-water, as shown at the point A A.

Both of these designs have advantages peculiar to themselves: that at diagram 107 is in use generally on the Eastern Jumna Canal, piles being substituted for masonry revetments on the curves B B; that of diagram 106 is new, and has not yet been tried. The latter, however, has the merit of being more compact than the original design, and of being greatly more economical in its construction. It was, in fact, the enormous excavations which were required at the falls at Belra, the difficulty of disposing of the earth, and laying out the embankments, and the extensive area demanding box-work at the tail, that led me to the modification as exhibited in diagram 106.

The outline shown in diagram 106 represents the falls which I am now describing: it will be observed that they are protected at the head by a consecutive line of sheet piling, between which and the body of the work frame-boxes filled with boulders are placed, the boxes and boulders being retained in position by sleepers nailed on to the pile-heads. A similar line of piles, it will be observed, connects the ends of the jetties forming the limit on the down-stream side, to the frame box-work and heavy material that occupies the space enclosed by the body of the work and the flank revetments. This protective area of heavy material has a slope of 1½ feet to the down-stream side. That on the upper levels, and which acts as an

apron to the whole front of the work, has a similar slope downwards to the up-stream direction. The flanks on the right and left, both at the upper and lower levels, are strongly protected by piling, the detail of which will be best understood by referring to the Atlas.

Independently of the deep lines of foundation on the up- and down-stream sides, built transversely across the canal, the thickness of the flooring over which the water passes is 6 feet; it rests upon very fair clayey soil, and, with the exception of the upper layers, is constructed entirely of boulders and lime cement; the revetment walls, piers, arches and superstructure generally, are of brick masonry.

The object of dividing the lower flooring into chambers by divisions walls, was to afford the means of repair; and for this purpose the cutwaters on the upper levels have been designed with grooves for the admission of sleepers or vane planks, which are let down from the roadway flooring by windlasses adapted to bittheads sunk into masonry blocks. This line of bittheads and windlasses, with nests of sleepers packed below them, acts as a parapet to the roadway on the up-stream face of the bridge. On the down-stream face a masonry wall gives security to the line of communication.

Steps are attached to the wings of the bridge, so as to give the means of access to the platform on the top of the flank revetments; and flights of steps supported on flying arches, enable the establishment to reach the top of the division walls from the upper roadway. No. 2 falls being situated on the high road between Saharunpoor and Hurdwar, has a bridge roadway equal in width to 25 feet.

The cement used in this work was composed of—

1 part stone lime.
1 part soorkee.
1 part sand.

The total quantity of material used, and the rates of the different species of work, are exhibited in the following table:—

Bricks (12″ × 6″ × 2½″)				923,500
Do. (12″ × 6″ × 2″)				728,900
Boulders				317,225 maunds.
Jhama				10,919 cubic feet.
Stone lime				75,310 ,,
Soorkee				71,418 ,,
	RS.	A.	P.	
Masonry of all sorts	12	9	4	per 100 cubic feet.
Plaster	4	13	11	per 100 superficial feet.

These works were built under the superintendence of Captain Goodwyn, and cost, exclusive of regulating apparatus, which has still to be fixed, Company's rupees 72,788-8-11.

No. 3. Bahadoorabad falls are constructed at a point in the canal alignement where there is a deviation of 5½° from the direct line: to meet this obliquity, and to give the current a bearing upon the new direction, a corresponding obliquity has been given to the flank and chamber walls: the plan of construction may be understood from the figure in Plate XXII. of the Atlas, where the lining out of this work is shown *in extenso*. The work is, in fact, built on a curve, the segment of a circle whose radius is 960 feet. With the exception of the peculiarity in the lining out, the details of building, both in material and dimensions, are precisely the same as those at the No. 2 falls. The depth to which the curtain or foundation wall on the upper level is carried, and that of the tail and its flank revetments and jetties, is equal to 20 feet.

The cement used in this work was composed of—

1 part stone lime.
1 part soorkee.
1 part sand.

The total quantity of material used, and the rates at

which the work has been executed, are exhibited in the following table:—

Bricks 12″ × 6″ × 2½″				1,431,220
Boulders				326,088 maunds.
Jhama				7,910 cubic feet.
Stone lime				75,993 „
Soorkee				77,670 „
	RS.	A.	P.	
Masonry of all sorts	11	7	1	per 100 cubic feet.
Plaster	4	3	5	per 100 s. feet.

These works were also built under the superintendence of Captain Goodwyn, and cost, exclusive of the regulating apparatus, which has still to be fixed, Co. rupees 67,613–10–3.

II. *Falls with a Drop of* 8 *Feet.*

Under this item, are included the whole of the masonry falls, extending from Assoffnuggur to Dasua, or from the 24th to the 106th mile. They may be divided into two series, depending on their width of waterway; the first series being of equal extent to that of the Khadir works; the second being diminished in consequence of the reduction of theoretical volume in the canal, depending on the abstraction of 1,240 cubic feet per second for the Futtigurh branch supply; on the expenditure from rajbuha heads; and on other causes depending on escapes. No reduction, however, takes place until the channel has passed the leading escape at Khutowli, up to which point it is liable, on emergency, to be loaded with water (which may be turned off from the above branch) in addition to its own supply.

The falls, therefore, in this section, may be classed under the following heads:—

First series, with a waterway of 200 feet in width—

Assoffnuggur Falls, at the 24th mile.
Muhmoodpoor Falls, at the 31st mile.

Belra Falls, at the 42nd mile.
Jaoli Falls, at the 48th mile.
Chitowra Falls, at the 55th mile.

Second series, with a waterway of 150 feet in width—
Salawur Falls, at the 68th mile.
Bhola Falls, at the 84th mile.
Dasna Falls, at the 106th mile.

With exception of additional height to the bridge superstructure, which is dependent on the elevated embankments and depth of digging, the design for the works in this first series is similar in every respect to that of the falls in the Khadir which I have before described. The Belra Falls, which I have pointed out as a solitary instance of deviation from the general plan in the flank and tail arrangements, is in other respects also similar.

In accordance with the views which have guided me in drawing up this report, I shall, at the risk of being considered tedious, enter into a brief detail of the different works, noting the peculiarities connected with soil and foundations, quality of material used in their construction, and variations in the details of design, which although trifling in themselves, may hereafter be useful if placed on record. To commence, therefore, in the order of precedence, we have as first on the list:—

The Assoffnuggur Falls.

This work, which is situated at the 24th mile, is constructed on the plan figured in diagram 106. It is built entirely of brick masonry with stone lime cement. Its elevation is similar in design to those which have been constructed in the Khadir, with exception to the height of bridge piers, which have been elevated to bring the levels of the roadway in correspondence with those of the embankments. Its wing walls are flanked by a flight of

steps, which give the means of passage from the top of the banks to the berms: on the right and left of the main arches are recesses or niches, partly to give relief to the long line of wall, and partly to give cover. The bittheads, windlasses, and sleepers are on a uniform design to those used in the Bahadoorabad Falls.

The front line of piles and apron, and the protection given to the tail, and to the flank jetties, are on the same plan as before described; the heavy material by which the protection is given, being of boulders or round stones brought from the beds of the rivers in the Khadir.

The foundations are laid in sand of a nature so pure and unmixed, that had the excavations not been made in the high land, and at a distance from all drainage, one would have supposed that they had been sunk in the bed of a river. I may here draw attention to the quantity of sandstone concretions that were found irregularly distributed throughout the whole of the excavation connected with the sand deposits. In quality and on fracture they were *identical with the Sewalik sandstone*. They exhibited themselves in masses of no great size, but either in a *tabular or a stalactitical form*. *In drifts caused by wind*, reticulated, pipe-like lines of the same material, but in appearance resembling straws or roots, were a remarkable feature in these sandy beds. The formation is entirely distinct from that of the Kunkur deposits, which are intrinsically a recent limestone formed of lime and clay; they arise, in all probability, from aggregations of sand and lime, formed by some inexplicable laws of affinity. As these concretions have been found distributed throughout the sand on the whole line of excavations on the high country, it is convenient to refer to them in this place. The proportions of sand and lime appear to exist under great variations: in the northern districts the sand predominates, and the mass is a calcareous sandstone; in the

Alligurh, Mynpoori, Etawah, and Cawnpoor districts, where there is an excess of lime over sand, the concretions, which I observe in these cases assume a more massive and botryoidal form, although never exceeding a few inches in cubic content, are collected by the lime-burners, and on being burnt, produce, it is said, an excellent lime.

To revert to the foundations of the Assoffnuggur Falls, which, as I have before said, are laid in sand. The whole of the walls are constructed in hollow caissons arched over, and the ends of the jetties rest upon circular cylinders or wells 20 feet in diameter, sunk to a depth of 20 feet, and used during the construction of the building for the purpose of supplying water to the works; this plan has been universally adopted, and with great advantage on all occasions. The foundation wall in the front, or on the upper level, is 20 feet in depth, and 8 feet wide; that on the tail is 20 feet in depth, and 10 feet wide. The floorings between the foot of the ogee and the tail extremity are 6 feet in thickness; and the whole work is constructed on the massive dimensions exhibited in Plate XXXI. of the Atlas.

The bricks which were used were made in the vicinity, 12″ × 6″ × 2½″ in dimensions, and the proportions of the cement were as follow:—

1 part stone lime; and from
1 to 2 parts of soorkee, according to kind of work.

The quantity of material used, and the rates of building, are shown in the following table:—

Bricks (12″ × 6″ × 2½″)	34,67,766	
Bricks, small	1,50,000	
Boulders	8,236	maunds.
Jhama	6,250	cubic feet.
Stone lime	65,860	,,
Soorkee	85,135	,,

	RS	A	P	
Masonry, including everything	17	3	11	per 100 cubic feet.

The work, which was built under the superintendence of Captain Goodwyn, cost, without the regulating apparatus, which has still to be fixed, Co.'s rupees 91,419-0-6.

The Muhmoodpoor Falls.

The most remarkable feature in the construction of these works, was the extraordinary extent and minute fineness of the sand in which the foundations are laid. The sand, in fact, was of such a nature, that the whole building was laid in a vast crater or inverted pyramidal frustrum, it being next to impossible, without imminent danger to the workpeople, to attempt perpendicular excavations. This sand, as at Assoffnuggur, was accompanied by the concretions which have been before described. The front foundations, or those which lie transversely across the canal, and which act as a check upon the subaction of the water, are laid to a depth of 32½ feet, in a narrow wall gradually increasing in width to the higher level; this wall in its progress of construction was carefully embedded in well-rammed sand, an operation which proceeded uniformly with the bricklaying. The rear and cross walls were built in the caisson fashion as practised at Assoffnuggur. The bridge wings and attendant superstructure were laid over cylindrical wells sunk to a depth of 40 feet. The general detail of the rest of the work, both in dimensions and material, are similar to those at Assoffnuggur. The niches, which are built on the right and left of the main arches at the falls above described, are here pierced through the building, so that means of access are provided from the upper to the lower side of the bridge; the bridge wings are flanked by steps for the purpose of passage from the road to the berm platform, so that the up- and down- stream sides of the work are connected by free and open means of communication.

The front apron and the tail platforms, with all their attendant detail of piling and box-work, have been executed on these works with the greatest care, and, if possible, with greater attention to stability than elsewhere: the plan is the standard one, as described at Assoffnuggur.

The bricks which were used in this work were, generally speaking, newly made from kilns on the spot, 12″ × 6″ × 3″ in dimensions; a number of old bricks from the ruins of the Munglour fort were also put in requisition; but the floorings are coated with selected material, viz., the best burnt bricks which were especially laid aside for the purpose in the brick manufactories.

The piling and frame boxes are as usual of saulwood, and the heavy material with which the latter are filled consists entirely of boulders brought from the Khadir.

The proportions used in the cement were as follow:—

1 part stone lime.
2 parts Soorkee.

The quantity of material used, and the rates of building, will be found in the following table:—

—	Content of Work		Material expended.		
	Cubic feet of Masonry.	Superficial feet of Plaster.	Bricks of all sizes.	Stone Lime	Soorkee.
Masonry .	451,597	36,562	3,386,977	Cubic feet 75,266	Cubic feet. 150,532

	RS.	A.	P.	
Masonry of all sorts . .	12	10	6	per 100 cubic feet.
Plastering	4	14	2	per 100 superficial feet.
Metalling	6	4	7	” ”

The Muhmoodpoor Falls were commenced by Lieutenant Fraser of the Bengal Engineers. The superstructure, with all the wood and stone work forming the outlying protection to the work, were executed under the supervision of

Mr. Frederick Read; and the cost was, exclusive of regulating apparatus, which has still to be fixed, Co.'s rupees 80,496-5-8½.

The Belra Falls.

These were the first works of the sort that were commenced upon; I found the work lined out, and the tail foundation walls laid in, on my first inspection early in 1848.

It will be understood from what has been said before, that the design of the ground plan of the Belra Falls differs from that of all other works of the sort; the design is figured in diagram 107, and the whole work is represented in Plate C. of the Atlas.

The front line of foundations is laid to a depth of 25 feet, and that on the tail to a depth of 20 feet; these, as well as the different cross lines under the floorings, are on the caisson plan, as before noted. The soil, although sandy—the work being situated immediately on the extremity of a ridge of sand (bhoor)—is of tolerable consistency, and of a sufficiently tenacious nature to admit of fair excavated lines, without the inconvenience and evils that have been met with at Muhmoodpoor. The dimensions of the floorings, the elevation of the bridge and revetments, and the detail of the work generally, are on the standard model. The whole work is built of brick masonry, the bricks (12″ × 6″ × 3″) being burnt in kilns situated in the neighbourhood; here, as at Muhmoodpoor, the greatest care has been given to the selection of the hardest class of bricks for the floorings, ogees, and those parts of the structure which are opposed to the constant attrition of water.

The protection arrangements, both on the upper and lower levels, are executed on the standard plan, and the boxes have been filled with block kunkur and boulders,

the procuring of which, at this detached work, has been a matter of very great difficulty.

The extent of excavation, adapted to the plan on which the tail revetments of this work are built, is very great, and the amount of work in the piling and tail platform proportionately so. A comparison between the areas represented in diagrams 106 and 107 will show that the first is to the last as 1 is to 1·4809, or that the quantity of work in the tail of the Belra Falls is half as much again as that in the others: I have noted on the face of the diagrams the actual areas of the tail floorings.

The proportions used in the cement were as follow:—

2 parts of earth lime.
1 part of Soorkee.

The total quantity of material used, and the rates at which the work was built, are shown in the following table:—

—	Content of Work.		Materials expended.		
	Cubic feet of Masonry.	Square feet of Plaster.	Bricks of various sizes.	Earth Lime.	Soorkee.
				Cubic feet.	Cubic feet.
Masonry .	396,370	36,562	2,972,775	132,123	66,062

	RS.	A.	P.	
Masonry of all sorts, including plaster	13	4	4	per 100 cubic feet.
Metalling	6	10	2·7	per 100 super. feet.

The Belra Falls were commenced under Lieutenant Fraser's superintendence, and were brought to completion by Mr. Read, by whom all the protection arrangements have been executed. The cost of the work was, exclusive of the regulating apparatus, which has still to be fixed, Co.'s rupees 77,523-3-9.

The Jaoli Falls.

These works are similar to those at Muhmoodpoor, but the soil in which they are founded is of a superior

description; the front foundation or curtain wall is $32\frac{1}{2}$ feet in depth, and 8 feet broad; the rear or tail wall is 20 feet deep; the design is on the caisson system, which is extended throughout the whole work. In elevation and dimensions the design corresponds with the standard plan, of which the falls at Muhmoodpoor are an example.

The piling and protective arrangements are similar in every respect to those before described, the heavy material with which the boxes are filled consisting of kunkur blocks.

The main mass of this building is formed of new bricks, with a proportion of the small native brick, excavated from ruins in the neighbourhood. The mortar consists of the following ingredients:—

2 parts of earth lime.
1 part of Soorkee.

The quantity of material used, and the rates of the work, are as follow:—

	Content of Work.		Materials expended.		
	Cubic feet of Masonry.	Superficial feet of Plaster.	Bricks of various sizes.	Earth Lime.	Soorkee.
				Cubic feet.	Cubic feet.
Masonry .	367,180	36,562	2,753,475	122,377	61,188

	RS.	A.	P.	
Masonry of all sorts . .	12	7	8	per 100 cubic feet.
Plaster	4	0	4	per 100 superficial feet.
Metalling	7	1	2	per 100 cubic feet.

The Jaoli Falls were commenced by Lieutenant Fraser, and finished by Mr. Read, under whose supervision the whole of the protective arrangements have been executed. These works cost, exclusive of the regulating apparatus, which will be fixed hereafter, Co.'s rupees 61,368-11-$10\frac{1}{2}$.

The Chitowra Falls.

The depth of the front curtain foundation wall of this work is equal to 14¾ feet, on a width of 8 feet. The rear or tail wall is 8¾ feet deep, on a width of 4 feet. In other respects the design is identical with that of Jaoli.

This work is constructed almost entirely of the native small brick procured from the ruins of the old town and serai of Chitowra. The floorings, ogees, and other parts subject to the attrition of the current, have a superficial covering, 12 inches in depth, of the best burnt new bricks selected for the purpose.

The frame-boxes which constitute the protection to the head and tail of this work, are filled with one-foot cubes of brick masonry, no other material being available. The piling and woodwork in general are executed on the standard plan.

The cement used in these works consists of the following ingredients:—

2 parts of earth lime.
1 part of Soorkee.

The quantity of material used, and the rates of the work, are as follow:—

—	Content of Work.		Materials expended.		
	Cubic feet of Masonry.	Superficial feet of Plaster.	Bricks of various sizes.	Earth Lime.	Soorkee.
				Cubic feet.	*Cubic feet.*
Masonry .	316,995	36,562	2,377,472	105,664	52,832

	RS.	A.	P.	
Masonry of all sorts . .	11	12	9	per 100 cubic feet.
Plaster	3	3	6	per 100 superficial feet.

The Chitowra Falls were commenced under Lieutenant Fraser's and completed under Mr. Read's super-

intendence; their cost was, exclusive of the regulating apparatus, which will be fixed hereafter, Co.'s rupees 55,132-13-2.

With the Chitowra Falls, the first series, or that with a width of waterway equal to 200 feet, terminates. In advance there is a reduction of 50 feet to the width, which brings us to the second series, which commences with—

The Sulawur Falls.

This work is situated at the 68th mile from the Myapoor regulator. With a new series in dimensions, we here begin a new series of form for foundations, spring-water being met with at moderate depths. In the tail walls, blocks have been used universally.

The design of these works is, with the exception of the reduction to waterway, which leads to a reduction in the number of arches, precisely the same as that in the former series. Here we have six bays of 25 feet each, instead of eight, as in the former case, and three chambers instead of four; the elevation and arrangement of parts is in other respects identical with the larger class of falls. Neither this, nor the protective arrangements, therefore, which are also on the same plan, demand any further description.

The soil at the Sulawur Falls is superficially good, but it reaches the sandy strata at moderate depths from the surface. The spring-water is in pure sand, through which the blocks have been sunk. The curtain or front wall rests upon the spring level, at a depth from the canal bed of 12½ feet; it is constructed, on the plan before described, in caissons; immediately in front, with their heads covering the lower part of this curtain wall, a line of sheet piling has been driven to a depth of 18 feet. The tail foundations rest upon a line of blocks, which are

sunk to a depth of 12½ feet. Both front and rear lines of piles, and boxes filled with heavy material, act as guards to the work from the action of the current; the details of these protective arrangements are similar to those before described. Blocks of kunkur, procured from the quarries in the neighbourhood, have been used as heavy material for filling the boxes.

The Sulawur Falls are entirely built of new brick, 12″ × 6″ × 3″, burnt in the kilns in the neighbourhood; and those parts which are liable to attrition of current are built of selected material.

The mortar consists of the following ingredients:—

2 parts of earth lime.
1 part of Soorkee.

The quantity of material used, with the rates of the work, are:—

—	Content of Work.		Materials expended.		
	Cubic feet of Masonry	Super. feet of Plaster.	Bricks of various sizes.	Earth Lime.	Soorkee.
				Cubic feet.	Cubic feet.
Masonry .	325,368	24,114	2,440,260	108,456	54,228

	RS.	A.	P.	
Masonry of all sorts, including plaster .	13	12	8	per 100 cubic ft.

The falls at Sulawur were built under Mr. Read's superintendence, and cost, exclusive of regulating apparatus, and a little work to finish off, Co.'s rupees 57,885-0-9.

The Bhola Falls.

This work is identical with that at Sulawur; the front curtain wall is sunk to a depth of 16¼ feet, with the standard dimensions in width. The tail rests upon blocks which have been sunk to a depth of 21½ feet.

In design of superstructure, thickness of floorings, protection to the upper and lower levels, and general arrangement of its parts, it is in no way different from the work last described. Blocks of kunkur have here also been used in the protective arrangements.

The whole of this work is built of newly-burnt bricks, and it it was during the whole period of its construction under the eye of a European supervisor, who lived on the spot; it has, therefore, if European aid is superior to native, been built under great advantages.

The soil was similar to that at the Sulawur works.

The cement used consisted of the following ingredients:—

2 parts of earth lime.
1 part of Soorkee.

The total quantity of material used, and the rates of the work, are exhibited in the following table:—

—	Content of Work.		Materials expended.		
	Cubic feet of Masonry.	Superficial feet of Plaster.	Bricks of sizes.	Earth Lime.	Soorkee.
				Cubic feet.	Cubic feet.
Masonry .	331,105	24,114	2,483,287	110,368	55,184

	RS.	A.	P.	
Masonry of all sorts, including plaster	15	11	9	per 100 cubic feet.
Metalling	5	2	8·9	" "

The Bhola Falls were built under the superintendence of Mr. Read, and cost, exclusive of the regulating apparatus, which has still to be fixed, Co.'s rupees 65,520-6-8¾.

The Dasna Falls.

The same remark applies to this as to the last work; the front curtain wall is sunk to a depth of 20 feet, on

the standard dimensions and design. The rear tail wall is laid in to a depth of 12 feet without the use of blocks, the brickwork being laid upon the spring level. In other respects, both in elevation, and in the arrangements of its parts, it is the same as the works at Sulawur and Bhola.

In digging the foundations of the left jetty, or the terminal extremity of the revetment on the left down-stream side, an apparently isolated piece of quicksand was met with. Blocks might with advantage have been used at this particular spot, but the appliances were not at hand, and it was considered that a platform resting upon the heads of piles driven a depth of 12 feet, and at close intervals, would have been sufficient for the stable support of the superstructure. A slight settlement, however, took place within six months after the work had been completed, showing itself in a perpendicular crack about 38 feet from the tail end of the jetty. After inspecting the part affected, and from the nature of the piled foundations, considering that it would be next to impossible to remove them, I adopted the following plan of repair, the value of which must be judged of hereafter. As the most distinct method of explanation, I here give an extract from my memorandum addressed to the engineer, Mr. Read, on his reporting that he doubted the possibility, with the means in his possession, of extracting the piling which had been driven, even if the masonry of the fractured end was pulled down and removed, for the purpose of rebuilding it :—

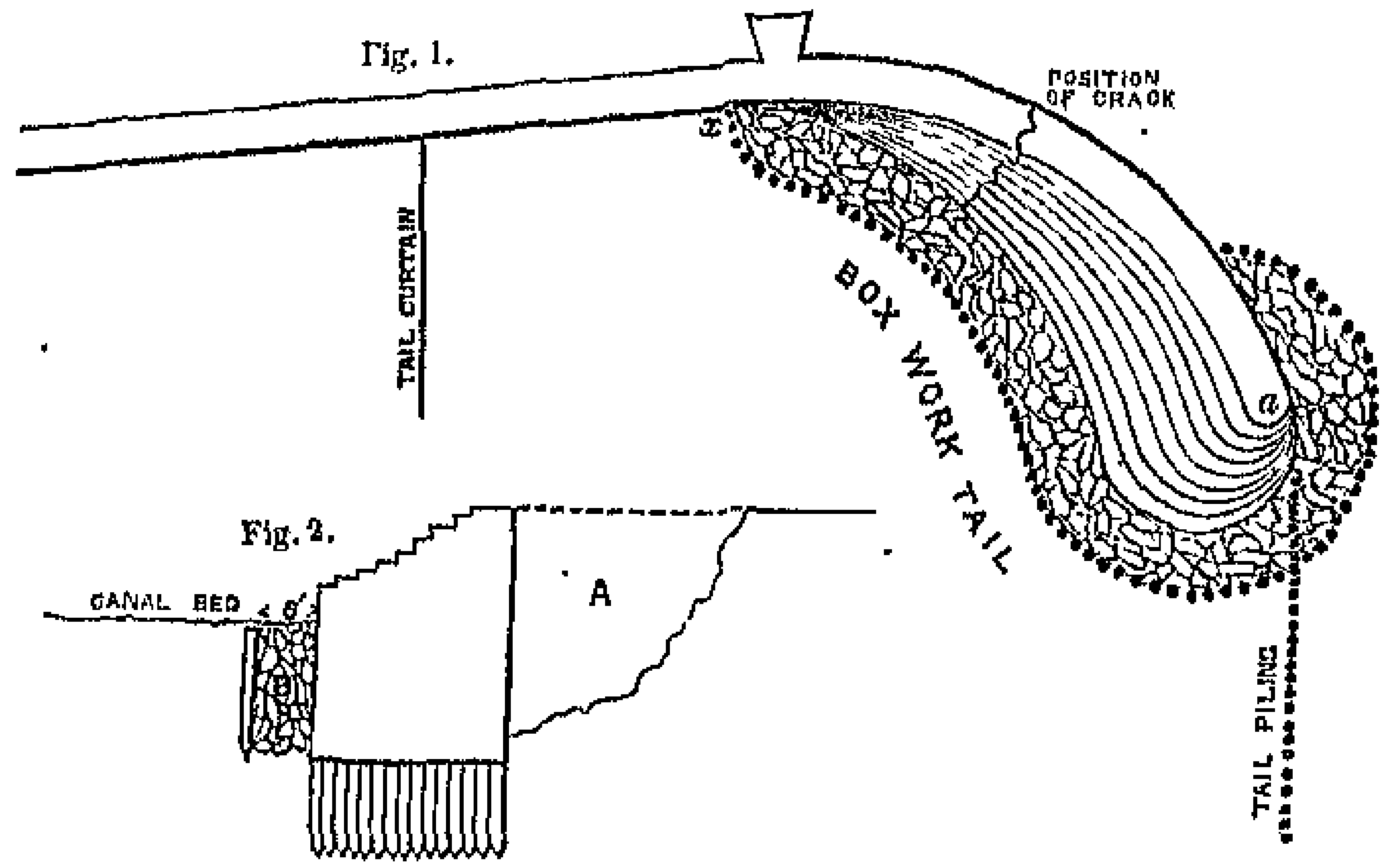
(Extract from memorandum, No. 119, dated 7th Dec. 1852.)

"1st. To let the wall stand as it is at present.

"2nd. To drive a line of 12 feet kurries, or sheet

piling, at a distance of 6 feet* from the foot of the wall, as shown in the following diagram :—

Diagram 108.

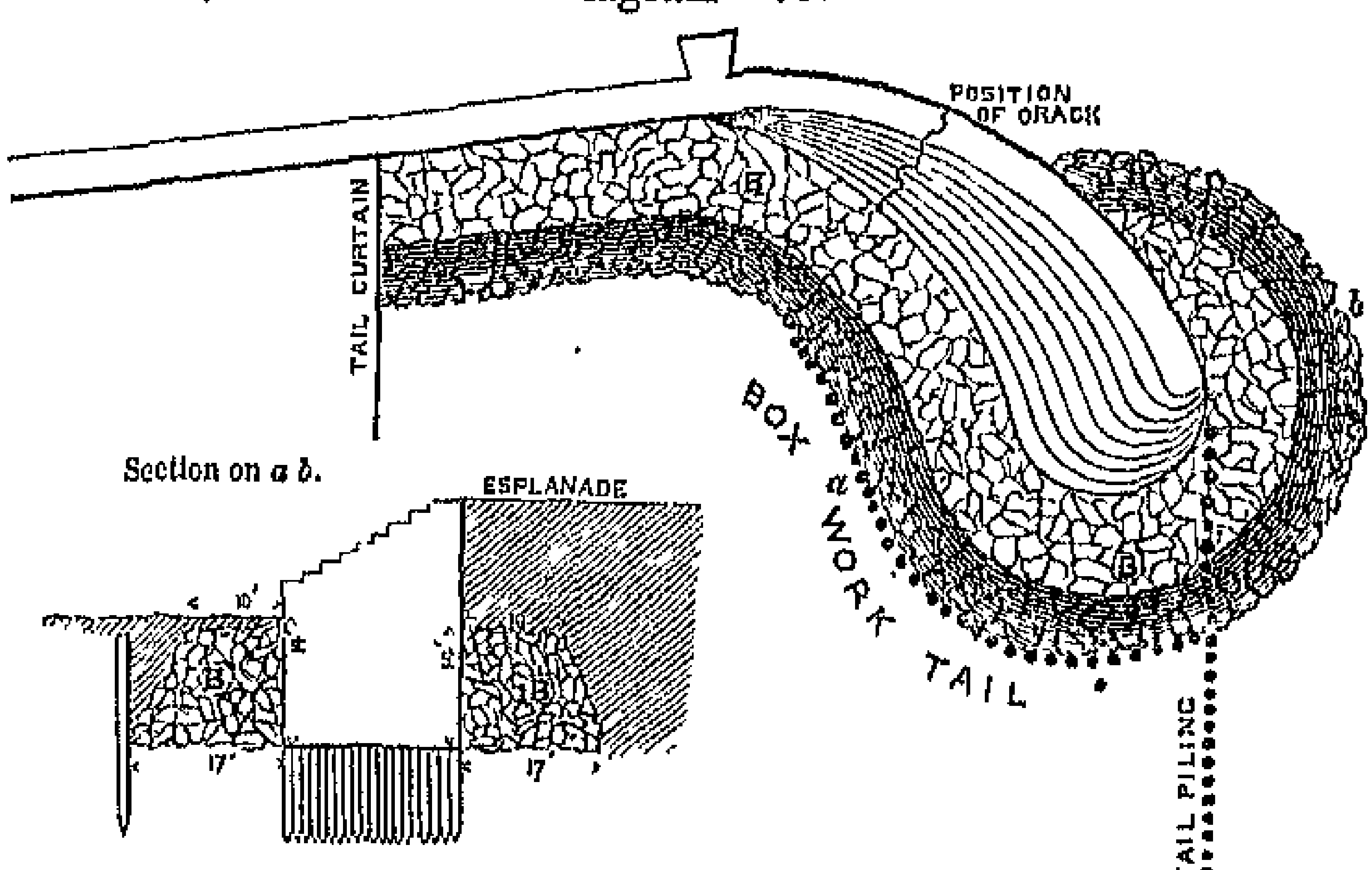


A. To be dug out when laying in the front. B. Rubble masonry.

"3rd. When the line of sheet piling is completed, the soil between it and the body of the wall is to be dug out

* This line of piling was subsequently abandoned, there being reason to suppose that the force employed in driving the piles acted injuriously on the masonry. The repair actually made is represented in the following diagram :—

Diagram 109.



B B. Rubble masonry.

as deeply as possible, and the space so dug out is to be filled in with rubble masonry, with lime cement (see fig. 2). This must be done very carefully, it must be executed in bits commencing from the end *x*; if there is any inattention on this point, and the foundations of the wall are left bare and exposed on long lines, the superstructure of the wall may fall forwards. To prevent any possibility of such a catastrophe, Mr. Read is advised to remove the earth from the rear of the superstructure, so as to relieve the walls from thrust as much as possible."

The crack at the extreme end of the lever (the settlement having taken place apparently at *a* in the above diagram) did not exceed a quarter of an inch; but as this particular part of the work is opposed to all the violence of the current, a flaw of the sort which occurred could not have taken place at a worse point.

The massive parts of the foundations and floorings of the Dasna Falls are built with blocks of kunkur; the rest, including the superstructure, has been entirely constructed of newly-burnt bricks of the standard size, 12″ × 6″ × 3″, as made in the puzawa or native brick-kiln. The cement which has been used is made of the following ingredients:—

Pure kunkur lime.

The quantity of material used, and the rates of the work, were as follow:—

—	Content of Work.		Materials expended.	
	Cubic feet of Masonry.	Superficial feet of Plaster.	Bricks of sizes.	Kunkur Lime.
				Cubic feet.
Masonry	304,886	24,114	2,286,645	152,443

	RS.	A.	P.	
Masonry of all sorts, including plaster	13	7	3	per 100 cubic feet.
Metalling	7	5	7	,, ,,

This work also had the advantage of the constant attendance of a European officer, who lived on the spot during the whole of its construction, and who saw the work in its daily progress. It was begun and completed under the superintendence of Mr. Read; and cost, exclusive of regulating apparatus, which has still to be fixed, Co.'s rupees 54,639-12-8.

The above gives as concise a description as possible of the falls with a drop of 8 feet, as included in Section II., and which are confined entirely to the line of the main canal lying above the head of the Bolundshuhur Branch.

III. *Falls with a Drop of 5 feet.*

This section includes two descents near the village of Pulra and Simra, which are consequent on the general depression of the surface of the country, at the heads of the Seyngoor and the Rinde Rivers; they are situated at the 149th and 164th miles of the course of the main canal. The Moonda Khera escape, with a waterway of 60 feet in width, lies at a point eight miles on the upstream side of these descents, and three miles below them is the Kasimpoor escape, a work on the same dimensions as that at Moonda Khera.

The Bolundshuhur branch head, which abstracts from the main canal 520 cubic feet per second, is situated 38 miles above the falls; and the Koel head, which is of the same dimensions as that at Bolundshuhur, lies between them at a point three miles below the first descent.

From the Dasna Falls, which terminate the last series, to the head of those at Pulra, which commence the present one, the distance is equal to 43 miles. The Pulra and Simra Falls are separated by a distance of fifteen miles.

By describing the precise position of these works relatively to the branch and escape heads, their value will be more perfectly appreciated. I have before alluded to the power that we hold in our hands of relieving the falls entirely from water by the proper adjustment of the branch heads, and that of the Moonda Khera escape; and of the further power which the escape at Kasimpoor offers of regulating the supply of the Nanoon regulators. We now, therefore, proceed to a description of the falls themselves.

The general design is similar to that which has been before described. The width of the waterway has been reduced to 100 feet (to meet the reduced capacity of channel), divided into five bays of 20 feet each, each bay having its corresponding chamber on the tail floorings. The proportions of the work generally have been adapted to the locality in which it has been built: in other respects the falls at Pulra and Simra are a mere counterpart of those which have gone before them. The works which I am now about to describe, therefore, are as follow:—

Falls with a waterway of 100 feet in width.
Pulra Falls, at the 149th mile.
Simra Falls, at the 164th mile.

The Pulra Falls (vide *Atlas, Plate XL.*)

This work has, as will be understood from the preceding paragraph, a waterway of 100 feet in width, divided into five bays of 20 feet each; the roadway is formed by segmental arches of 60° which are thrown over the bays so as to form a passage of 21 feet wide; the piers are prolonged on their down-stream side, so as to divide the flooring into chambers of 20 feet in width; and the up-stream face of the bridge is fitted with shutters, so that

in case of emergency, a chamber may be closed. There are the same facilities of access given to the different parts of the works by means of flights of steps and arched passages on the flanks of the main bays as are given in other buildings of this description, and the flank revetments and jetties are constructed in the form represented in diagram 106.

The foundation walls are built solid, and not in the caisson fashion before described; the front or curtain wall is sunk to a depth of 15 feet. The flank revetments and jetties rest on foundations laid at a depth of 13 feet below the canal bed.

The abundance of kunkur, quarries of which are numerous in the Bolundshuhur and Alligurh districts, enabled us to dispense with piles and wood-work, the cost of which would have been considerable. The protective arrangements on the upper and lower levels, which in former cases I have described as consisting of lines of piles, and frame box-work, are here exchanged for solid kunkur floorings, the lines of piles being represented by consecutive walls, and the frame box-work by unbroken sheets of the largest procurable kunkur blocks.

The falls themselves, with the exception of the bridge arches and those parts of the structure where it was most convenient to use brick, have been entirely built of kunkur. The ogees and floorings have a surface 6 inches in thickness of the best brick masonry.

The cement consisted of the following proportions:—

1 part of kunkur lime to
1-20th of white stone lime.

In excavating the foundations for the locks which lie parallel to the Pulra Falls, beds of kunkur had to be cut through; clay and a reddish earth locally called "kupcha," however, formed the predominant strata in the founda-

tions of the falls; the soil was of the best description that had been met with in founding works of this sort; and water was sufficiently close to the surface to admit of its free use in the works.

The quantity of material used, and the rates for building were as follow:—

	Content of Work.		Materials Expended.			
	Cubic feet of Masonry.	Square feet of Plaster.	3 inch Brick.	Block Kunkur.	Stone Lime.	Kunkur Lime.
				Maunds.	Maunds.	Maunds.
Masonry	174,375	43,274	221,141	128,802	117½	48,318

		RS.	A.	P.	
Rates.	Arch Masonry	12	0	0	per 100 cubic feet.
	Other Masonry	10	2	8	„ „
	Plastering	2	7	9¾	per 100 square feet.
	Metalling	2	0	0	„ „
	Bittheads	15	0	0	each.
	Windlasses	30	0	0	„

The Pulra Falls were begun and completed under the superintendence of Mr. Philip Volk, and cost—

	RS.	A.	P.
Masonry work	17,404	11	1
Protective works	1,630	12	10
Woodwork	240	0	0
Wood and Ironwork still to be completed	1,000	0	0
Total Co.'s Rs.	20,275	7	11

The Simra Falls.

These are a counterpart of those at Pulra, with slight deviations in the foundations arising from the contiguity of spring-water level to that of the canal bed. The curtain or upper foundation walls of the Simra Falls are 15 feet in depth, and consist of a plain line of solid masonry 6½ feet wide. The tail foundations are laid on blocks sunk to a depth of 15½ feet.

Kunkur has been used freely here as at the Pulra Falls: it may, with the exception of the floorings and arches, be considered the staple material of the building.

The cement is of the following ingredients:—

1 part of kunkur lime, to
1-20th part of white stone lime.

The *quantity of material used, and the rates of* building are shown in the following table:—

	Content of Work.		Materials Expended.			
	Cubic feet of Masonry.	Square feet of Plaster.	8 inch Bricks	Block Kunkur.	Stone Lime.	Kunkur Lime.
				Maunds	Maunds.	Maunds.
Masonry	186,063	45,059	276,304	122,790	198	50,417

Rates.		RS.	A.	P.	
	Arch Masonry	12	0	0	per 100 cubic feet.
	Other Masonry	9	14	3	" "
	Plastering	2	8	2½	per 100 square feet.
	Metalling	2	0	0	" "
	Bittheads	15	0	0	each.
	Windlasses	30	0	0	"

The soil in which these works are laid is of an inferior quality to that at the Pulra Falls, and the proximity of spring-water places them in connection with sand: the protective curtains, however, are built entirely of large masses of kunkur, laid in with cement, and are sufficient to relieve the work from all danger.

The Simra Falls were begun and completed under the superintendence of Mr. Volk, and cost—

	RS.	A.	P.
Masonry work	19,042	2	9
Protective works	1,604	12	10
Woodwork	240	0	0
Wood and Ironwork still required	1,000	0	0
Total Co.'s Rs.	21,886	15	7

This brings us to a conclusion on the subject of falls; the minor descents which I have described as existing on the Cawnpoor and Etawah terminal lines being unaccompanied by any works of sufficient magnitude to call for explanation. It will be satisfactory, however, to append a table of the calculated values of the falls above described, in connection with their theoretical discharge.

In drawing up this table, I have allowed the obstructions from piers or afflux, to cancel the value of initial velocity: the figures, therefore, actually exhibit the depths due to water pouring over weirs from a still basin. My calculations are based on the formula for this species of discharge; because both the afflux and initial velocity were necessarily variable quantities depending on the volume of water. Variable as they were, however, their effects were always in my favour, by tending to decrease rather than to add to the height or depth of water on the sill or wasteboard of the works.

The falls on the Eastern Jumna Canal, which are 50 feet in width, in one bay of 20 and two of 15 feet each, carry over their sills an average depth of 3 feet of water: the maximum may be considered as $3\frac{1}{2}$ feet, although occasionally in the rainy months the register rises as high as $3\frac{3}{4}$; the actual discharge under the above figures, and with the reservations above alluded to, is as follows:—

Width of Waterway.	Depth of Water on Sill.	Discharge in cubic feet per second.
Feet.	Feet.	
50	3·75	1,230·375
50	3·50	1,112·650
50	3·00	882·300

Excepting in extreme cases, and then only for short periods, the depth of water upon the sills of the Eastern

Jumna Canal Falls is 3 feet; it is frequently and generally in the lower divisions under this depth.

$$\frac{LD \times \sqrt{D} \times 5 \cdot 1 \times 2}{3} = \text{Discharge in cubic feet per second.}$$

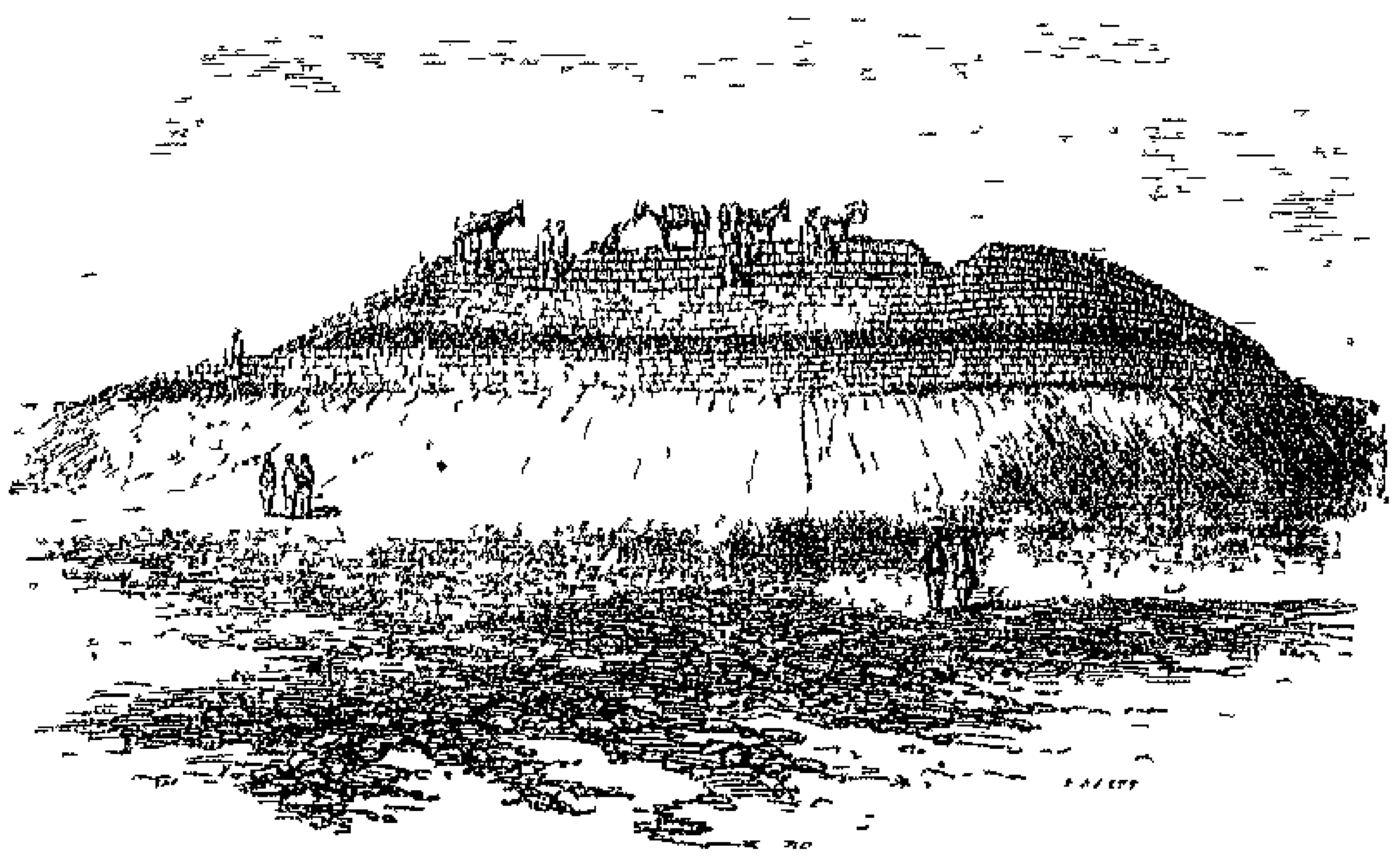
	Miles from Myapoor regulator.	Width of water-way.	Depth of water at the head of Falls.	Proportion of fixed supply which reaches the head of the Falls in cubic feet	Theoretical Discharge in cubic feet per second.
Assoffnuggur Falls	24	200	5	6,667·5	7,582·0
Muhmoodpoor Falls	31	200	5	6,585·0	7,582·0
Belra Falls . . .	42	200	5	6,502·5	7,582·0
Jaoli Falls . . .	48	200	5	6,120·0	7,582·0
Chitowra Falls .	55	200	5	5,097·5	7,582·0
Sulawur Falls . .	68	150	5	5,015·0	5,686·5
Bhola Falls . .	84	150	5	4,932·5	5,686·5
Dasna Falls . .	106	150	5	4,850·0	5,686·5
Pulra Falls . . .	149	100	5	3,994·0	3,791·0
Simra Falls . .	164	100	5	3,354·0	3,791·0

As the action upon the brickwork and floorings of the above works (with the design and construction of which I was familiar) was well known, and could after an experience of twenty years be well appreciated, I considered that, in the Ganges Canal Falls, we might with perfect security increase the above depth upon the sill *to 5 feet, or even as far as 6; but I adopted* the minimum quantity, as that to which we might more satisfactorily approximate. The disposition of works in the series of waterways above described is dependent on other causes than the discharge of the theoretical volume: to these I have before alluded in describing the position of outlets and contingencies of additional supply to the main channels from the closing of the branch heads. The massiveness of foundations is dependent on the nature of the soil, which, in most cases, is sand; it was not thought worth while, how-

ever, to alter in their minor details standard plans and recorded dimensions, for the purpose of adapting solitary works to their own particular locality.

The preceding table will show the amount of theoretical volume of water at the head of each of the falls, and the amount of discharge, supposing that the depth of water on the sill or upper platform of the ogee is equal to 5 feet. The formula used is that for discharges of water from reservoirs over side weirs or open sluices.

The amount of volume, as exhibited in the fourth column, is liable to a deduction of about 250 cubic feet a second, for water supplied to the navigable cut, which leaves the main canal above the falls: this deduction may be considered constant, as the navigable channel can only be kept in an efficient state by forcing a current through it.



PUZAWA, OR NATIVE BRICK-KILN
(2nd View)

Chapter III.

WORKS OF COMMUNICATION.

The regulating and other bridges forming part of the works at Myapoor and Dhunowri; those situated at the terminal lines at Nanoon, and at the Futtigurh, Bolundshuhur, and Koel branches, together with those connected with the falls and the different buildings for crossing the canal at the terminal works on the Ganges and Jumna rivers, are not included in this chapter. I confine myself here to bridges which have been built expressly for the convenience of the public, the description of those above mentioned having been included in that of the works of which they form component parts.

For the convenience of reference, I shall place the works which are here to be described in sections, as in preceding chapters, devoting the leading one to "Centerings," a position which it naturally occupies in connexion with bridge building generally; and in the Ganges Canal works particularly, where economy of time, as well as of money, had a most material influence in the progress of the works. It was one which accordingly demanded the earliest consideration. Under this view, the present chapter is divided into the following sections:—

I. Centerings.
II. Bridges between the head of the canal and Roorkee.

III. Bridges between Roorkee and the Nanoon Fork.
IV. Bridges on the Terminal Lines between the Nanoon Fork and the Terminal Works.
  A. Cawnpoor Line.
  B. Etawah Line.
V. Bridges on the Branches.

I. Centerings.

These may be separated into two classes; the first, consisting of timber, or the method usually adopted in Europe; the second of earth, or a combination of earth with brick ribs, as common to India. On the Ganges Canal Works, the above classes may be thus described:—

Class I. A. Centerings used at the Myapoor Head Works.
  B. Centerings used in bridges of 55 feet span in the Khadir Works.
  C. Centerings used on the high land of the Doab.
  D. Centerings used at the Solani Aqueduct, and at the Falls in the Khadir or Northern Division of the works.

Class II. A. Simple centerings of earth.
  B. Compound centerings of earth, and ribs composed of a rigid material.

Before proceeding with a description of the above, I may remark, that the rule adopted in all cases, was to relieve the arch slightly as soon after the keying was effected as possible; to continue this relief gradually and according to the circumstances of the particular case, but invariably to have the centering removed entirely within a month after the arch was keyed.

Class I.

(A. *vide* Sheet 1, Plate XLII. of the Atlas.) This design was put into practice throughout the works at the canal head at Myapoor. With centerings of this description, the arches of the regulating bridge of the Boolma inlet, and of the small bridge that lies on the nulla of that name above the inlet, were built. The span is 20 feet, and the ribs, ten in number (placed 4 feet apart), were supported on temporary pedestals made of brick and mud, erected close upon the piers. The ribs rested on a striking apparatus consisting of the usual double wedge or pyramidal shaped bolts, which were supported by the above pedestals. The results appear to have been satisfactory, although I have no record of the action upon the arches on the removal of the centerings. The arches are built in three concentric rings, 6 inches in depth each, and are consequently without voussoir: their curve is a segment with a rise equal to 4 feet, or to 1-5th of the span. Newly-made bricks 12″ × 6″ × 2½″ were the material used. These centerings were designed by Lieutenant Richard Strachey, of the Bengal Engineers.

(B. *vide* Sheet 2, Plate LXII. of the Atlas.) The whole of the 55 feet span arches in the Khadir and Northern Division have been built with this species of centering; its great merit consists in its being made with the kurri or staple rafter brought from the Sewalik forests; in the kurries not being pierced or injured by tenon and mortice; and, consequently, by their being available for other purposes afterwards. The design is an excellent and a most economical one; it is due to Lieutenant Yule, of the Bengal Engineers.

The method of fixing the ribs in position was here (allowing for the excess of width) much the same as in the former case. In addition to the flank, there were

three intermediate pedestals, upon which the striking apparatus, similar to that used at the Myapoor works, rested, and the process of striking was performed on the plan above explained. These arches, although exhibiting on the intrados an elliptical curve, are all perfect segments of circles, with the voussoirs of brick courses radiating to one centre: the construction in this respect is shown in Fig. 3 of Sheet 2, Plate LXII.; they are built with large bricks $12'' \times 6'' \times 2\frac{1}{2}''$; the thickness of the brick being in some cases three inches. In the volume of tables, Appendix I., a return will be found of the amount of subsidence of the crown of each of these arches, following the removal of the centerings. During the construction, I am not aware that any settlement was observable; and the terminal bridges of the Solani Aqueduct, which were built with these centerings (the up-stream one by Mr. Parker, and the down-stream one by Mr. Login), are two of the most satisfactory works of this sort that have been completed.

(C. *vide* Sheet 3, Plate LXII.) These were designed by Lieutenant Fraser of the Engineers, who had charge of the second division, in which the leading bridges next to those at Roorkee are included. The centering was only used on six occasions; the cost of carriage from one spot to another was found to be very great, and the delay attending upon its use was fatal to progress: after the completion of the six bridges at Munglour, Liburheri Dimat, Togulpoor, Belra and Bhopa, the woodwork was converted to other purposes, and the use of earthen centerings was adopted. The method of fixing the ribs and of striking the centerings needs no particular description; generally speaking, it was similar to that laid down for the guidance of executive officers, and practised in the former cases. The Munglour Bridge arches were in all their parts elliptical; their brick courses were laid in

voussoir from the five centres on which the intrados of the other bridges of this description were described: this is a solitary example of this species of arch; and as it so happened, the disarrangement on relieving it from its centering has been greater than elsewhere. The bricks used were 12″ × 6″ × 3″, laid carefully in voussoir, the bricks being cut for the purpose. The return of settlement of the crowns of all the bridges built with the above centering will be found in the Table.

(D. *vide* Sheets 7 to 9, Plate XXVII.) These centerings were designed by Captain Goodwyn of the Engineers; they have been used at the bridges on the heads of No. 2 and No. 3 falls in the Khadir, and on the Solani Aqueduct. As a detailed description of these centerings is given in the chapter devoted to the aqueduct (*vide* pages 496 to 499), it will be sufficient here to observe that the ribs rested on timber tressels, and that the striking was performed under the usual rules with regard to time. These centerings did their duty very effectually.

In all the above cases, the curved surface upon which the brickwork was laid, consisted of squared kurries (the common rafter of the country), laid transversely across the ribs, in close contact, but not fastened: over this dry soorkhi was thrown, partly to rectify irregularities, and to equalize the curve, and partly to prevent the adhesion of the kurries to the intrados on the sinking of the centering.

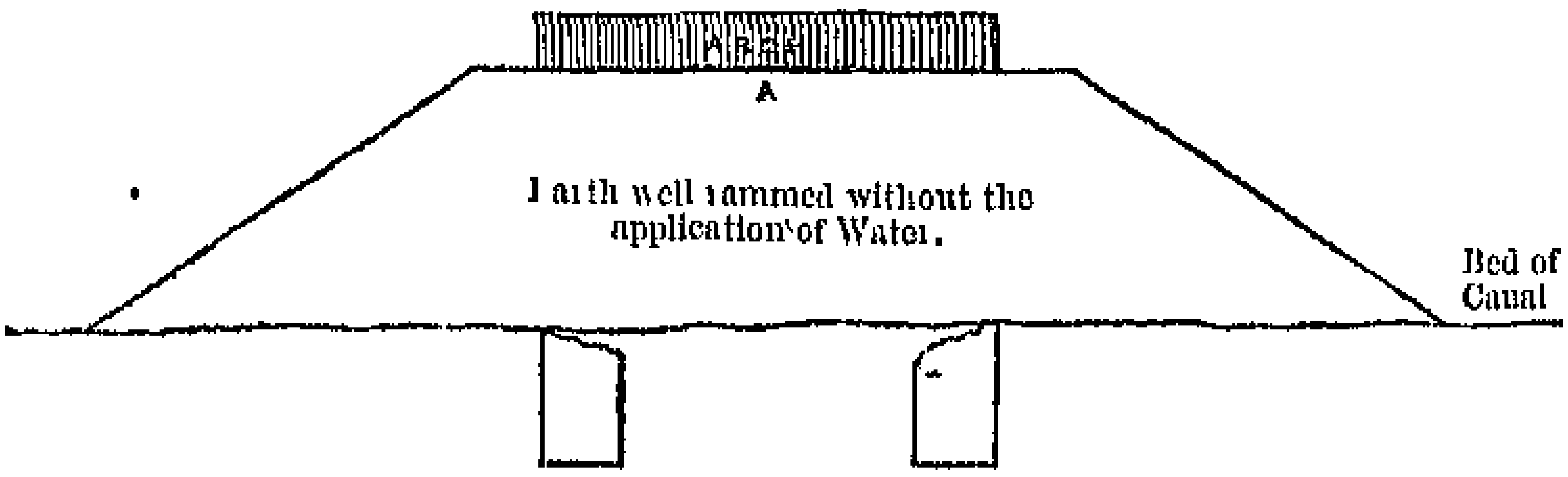
CLASS II.

A. The arches of all the bridges extending from the 47th to the 110th mile, were built on centerings of earth only; the design of which will be best shown in a diagram representing a bridge on its transverse vertical section through the crown of the arch.

With the exception of the eight bridges at the lower

extremity of the line on which this species of centering was used, the canal channel had previously to the construction of the arches been entirely cleaned out and excavated; this was rendered necessary from the sandy nature of the soil, which did not admit of rectangular sided excavations for piers or abutments; on the contrary, to prevent accidents from the subsidence of the sides, it was a matter of the utmost expediency to excavate on long slopes; and during the progress of the building of either the foundations of the piers and abutments, or of the curtain walls lying intermediately, to carry on a gradual process of filling in, the level of each day's work in masonry being met by a corresponding level in the replacement of the earth. In extreme cases,

Diagram 110.



therefore, when the soil in which the foundation walls were laid was pure sand, the whole of the area on which the masonry rested was one crater or hole, and on the completion of the above walls, the soil in their vicinity was necessarily loose and compressible; the floorings of the bays, therefore, were not built previously to the erection of the centerings, nor could the economy which will be noticed frequently, of constructing the centerings on the natural terreplein, be adopted. The course of proceeding in all the above-mentioned cases was as follows:—To complete the excavation of the canal, to finish the substructure of the bridge in all its parts (with exception to the bay floorings) up to the level of the top

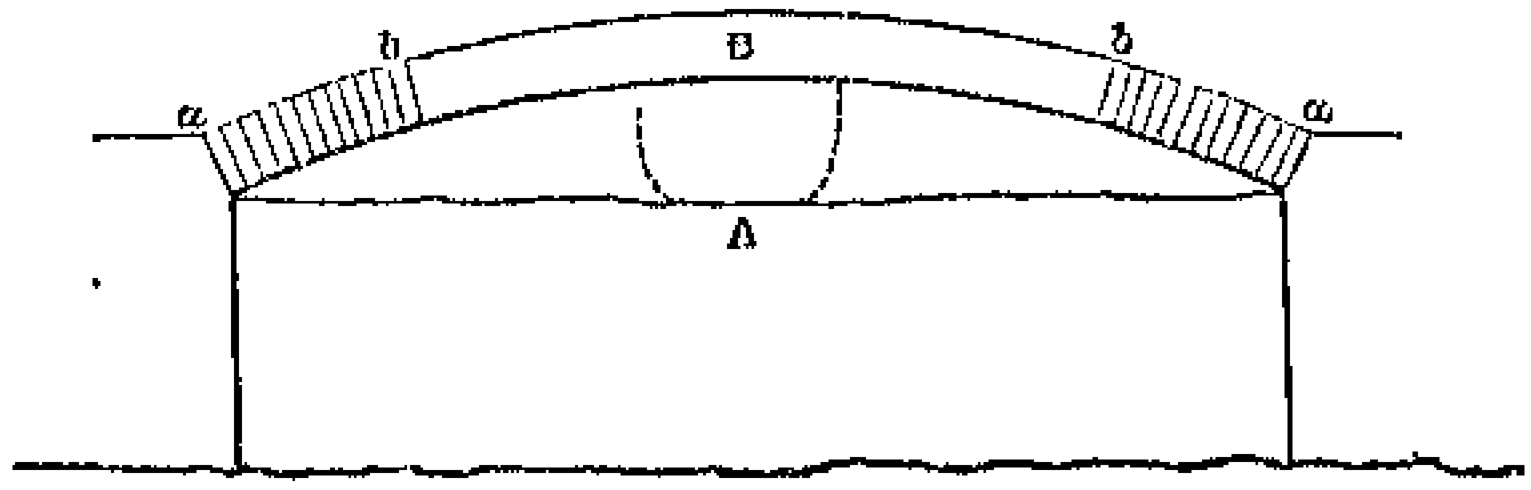
of the impost blocks; to fill the bays with earth, as shown in the preceding diagram; to form the upper part of the surface in the desired curve, and upon it to build the arch.

As the results of our loading trials with these centerings had a very material influence on the design for the centerings of the aqueduct, I must, at the expense of some detail, explain the circumstances under which this influence was exerted. The Solani Aqueduct consists of fifteen arches of 50 feet span each, the width, 192 feet, being divided in the centre, so that the arches might be constructed separately in widths of 96 feet each. To make timber centerings for such an extent of arch work, was not only expensive in itself, but, at the period in question, was considered to be a work of great time and labour: in the early part of our proceedings, therefore, I had intended to adopt earthen centerings similar to those in common use by the natives, and the only question that arose was, whether to make them of simple earth, or of a mixture of brick wall and earth. As far as economy was concerned, the saving of expenditure in using this simple species of centering would have been enormous; and although there were inconveniences in connection with the total stoppage of the waterway, which would have to be remedied by securing the completion of the arches, and the removal of the centerings during three months in the year when no floods could be expected, the plan had great advantages in other respects, and it had my decided support. Before arriving at any conclusions, however, it was advisable to see the results of the earthen centerings which were at that time in progress of construction below Roorkee; and although the weight of the arches of the 55 feet span bridges was less than that of those of the aqueduct, we should gain some practical information which might be of service. The results were

sufficiently unsatisfactory to lead me to discard this species of centering for the aqueduct arch; and I could devise no satisfactory method, either by brick ribs or by transverse walls, of qualifying the evils that were inherent in centerings of this description, without adopting *in extenso* the native method of building a rigid centering, and allowing it to remain until the masonry of the arch was indurated.

To explain the objections to the earth centerings, which appeared to me to be fatal to arches intended for the support of large bodies of constantly running water, I will, in diagram, show in elevation that which has been before exhibited in cross section.

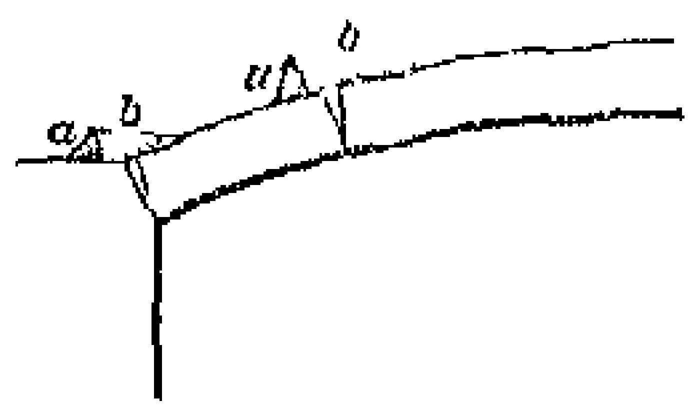
Diagram 111.



A represents the earth, of which the transverse section is shown in diagram 110. B represents the arch, in the construction of which the brick courses are laid from the skew-backs *a a*, inwards towards *b b*. Now, in building the arches, it was universally observed that when the courses of the brickwork had reached beyond the point of equilibrium, and immediately when the weight of the material began to act on the compressible centering, there was a tendency to downward action on two hinges, one of them at the skew-back, the other about four feet from it—at those points marked *a* and *b* in the above diagram: here there were distinct separations in the brickwork, increasing as the arch advanced towards its centre, the maximum width of opening as observed not exceeding one inch on the extrados, at the period

when the final measure of keying took place. During the operation of keying, and immediately afterwards on the earth being removed from the intrados of the crown, the separations above described *closed;* but, although this closing was to all intents and purposes as perfectly effected as it could well be, the line of separation was distinctly traceable along the whole width of the arch on its extrados; and I considered it advisable in every case to establish for a week or ten days over the line of separation a trough of lime-water, so that the continued percolation might restore the masonry to its original integrity.

Diagram 112.



a b. Trough. *a* Edging to retain water mixed with lime over the points of separation. *b*. Water mixed with lime.

However unimportant such a defect might be in arches for roadway purposes, I concluded that for an aqueduct carrying a depth of 10 feet of water, it was quite inadmissible: the aqueduct arches, moreover, being considerably heavier, would in all probability be attended by separations of a much more serious character. Earthen centerings for the aqueduct, therefore, were at once abandoned; and at this period the design which has been now carried out, and which was most opportunely suggested by Captain Goodwyn, the executive engineer of the works, relieved my mind from any further anxiety on the subject.

The earthen centerings, therefore, which were built in the 2nd division, were the experimental guides to those of the Solani Aqueduct, whilst in their own especial duties they acted satisfactorily, and were the cause of great saving both in time and expenditure.

The value of settlement of the crowns of arches in all the bridges where this species of centering has been used, will be seen in the table; and from this a comparative estimate may be made of the amount of depression in other cases.

I may observe, in conclusion, that immediately the arch is keyed, parties are placed so as to remove the earth from that part of the centering lying directly under the crown, or within the dots marked in the diagram: after the removal of this, it will be understood that that part of the centering lying to the right and left is easily got rid of; in fact, from its elevated position, the labourers are able to dispose of the earth, and throw it on the lower levels with little waste of time, and with little expenditure of exertion.

The arches in this series were, with the exception of the bridges of the 3rd class (as described in the following section), which were made with small native bricks, built entirely of new bricks, $12'' \times 6'' \times 3''$, with excellent mortar, used as sparingly as possible, and semi-fluid, whilst the bricks themselves had been, previously to their being laid in the work, well soaked in water.

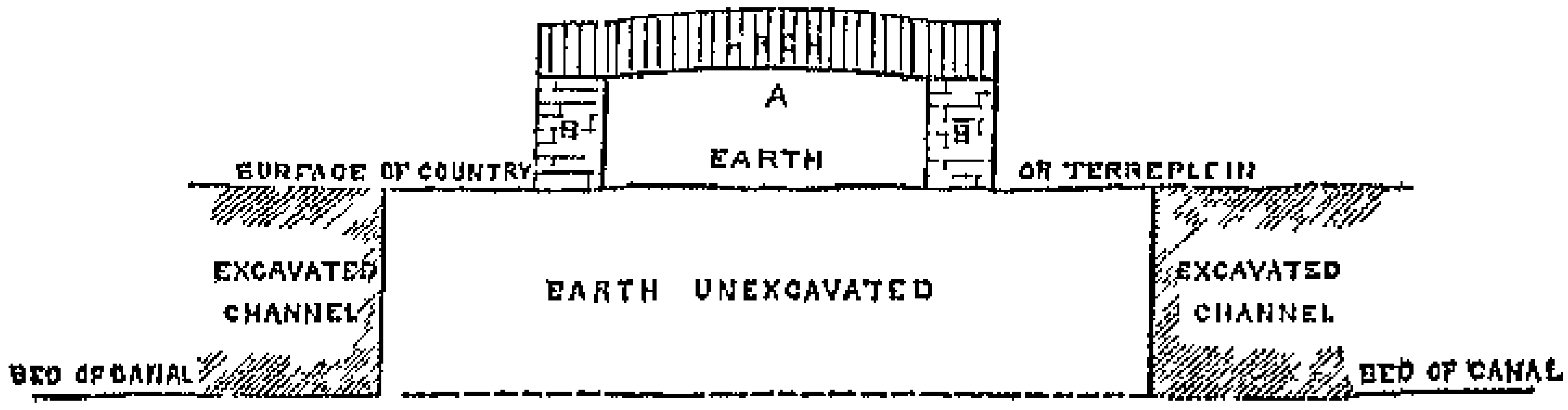
B. In the centering above noted, we have a material homogeneous, and, as far as earth is so, equally compressible on all the surface on which the arch is laid; in that which we are now about to describe, we have a mixture of rigid and compressible material, and in this respect theoretically inferior to the other; it has the advantage, however, of preserving the form of the arch in the true curve on which the segment is designed, and with proper management of maintaining a sufficient equilibrium in its parts, to prevent irregularity of depression. This species of centering has been used on the whole of the works from the 110th mile downwards, and has been practised with more or less success

in all the bridges where the span of the arches has varied from 45 to 20 feet in width.

The following diagrams will show the method of construction adopted in this particular case, where the natural soil and the terreplein are converted into a support for the centering, the artificial portion of which in many cases is limited to the curve upon which the arch is designed.

Diagram 113.

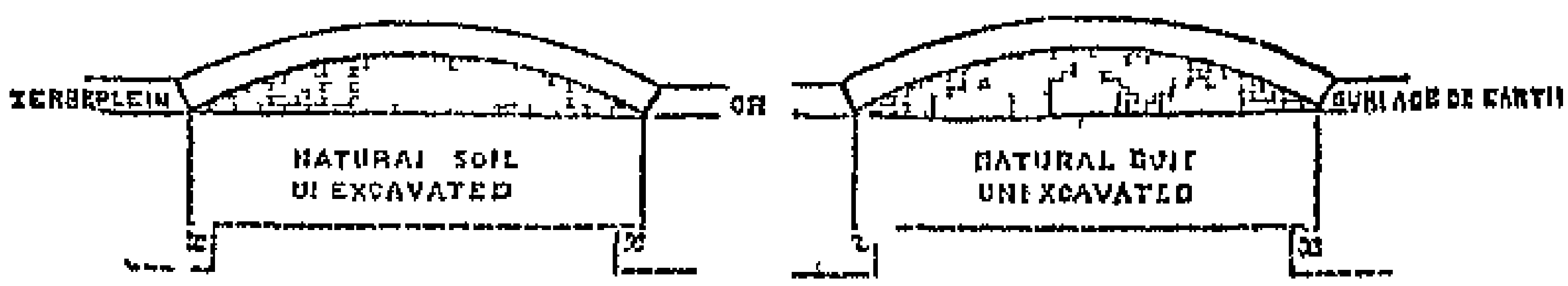
Transverse Section on Crown of Arch



A representing the earthen centre supported on each side by the walls B B, built of brick with mud cement, constructed in such a way that it can easily be separated

Elevations showing the above on different methods of construction, each of which is intended to facilitate the removal of the brick ribs from under the crown of the arch, as rapidly as possible, after the arch has been keyed, are exhibited in the following diagram :—

Diagram 111.



In both these cases it will be observed that the piers have been built with the natural soil between them unexcavated—the inner part of their foundations at x x being prepared for after construction and bond of the floorings and curtain walls, when the centerings and the earth which have been left for their support have been removed. The artificial portions of these centerings, therefore, are segments of circles corresponding in shape with those of the arch, which is to be built upon them. It has

been considered sufficient to give two examples of this species of centering; the brickwork, however, has been built in a variety of ways, all intended, as before said, to facilitate its removal; the omission of every alternate brick in the deepest part of the segment was found to be well adapted to the object in view; but in all cases the course that was followed in the plain earth centerings, of getting rid of the whole of that portion of the centering lying directly under the crown immediately after the arch was keyed, and afterwards clearing as quickly as possible from the centre to the sides, was strictly attended to.

It will be observed in diagram 113 that the earthen portion of the centering is slightly raised, technically cambered, a device that was found to be of great advantage in cases where the width of arch exceeded 21 feet; in such cases, there was an inclination in the brickwork to settle unequally, from the compressibility of the earth; an evil that appeared to increase directly as the distance from the lateral ribs. In very wide bridges, therefore, an intermediate brick segment might perhaps with advantage be used, so as to secure an equality in the settlement during the period when the arch was building. It is evident that, with the combination of compressible and rigid material which this species of centering involves, the immediate relief of the arch is indispensable; this, however, is so easily managed, that with proper care no delay ought to take place, and there can be no doubt that the curve is better maintained in cases where centerings of this sort have been used than in arches constructed on plain earth, unaided by brick ribs, which have settled down in a greater degree before they were keyed.

The process that succeeds the removal of the centerings is to excavate the natural soil upon which they are

built, and so to clear out the canal channel. The curtains and floorings of the bays are then built with as little delay as possible. By adopting this cheap plan of centering, however, the bridges are deprived of one of the elements (see page 214) in the leading rule of construction; that is to say, the arch is allowed to exert its thrust upon the abutments *before* the lower fulcrum is fixed.

With the exception of the few bridges in which block kunkur is used, the arches are built of brick of the size before described, with the usual care given in the free use of water. In every case, however, as far as my observation has gone, excepting in that of the skew bridges (25 feet span), of which I have no accurate record, the settlement of the crown of the arch after the centerings are removed, has led to a very slight separation of voussoir, at a point from six to twelve courses of brick from the skew-back. This separation is to be detected along the whole line of the extrados; whilst on the face of the arch underneath, or on the intrados where the hinge of this movement takes place, no trace whatever of separation is to be observed. In all cases (and exhibited at an earlier period, where the superstructure was hurried forward), subsequent settlement is shown by its action on the parapets.

The arches of the Ranipoor and Puttri super-passages were built upon centerings, on a similar plan to that which is here described; the extraordinary width of the arches in the former case, 210, and in the latter, 310 feet, called for peculiar care in making the earth as incompressible as possible; brick ribs were limited to the up and down-stream ends of the works; and the results have been very satisfactory: the effect upon the haunches, after the removal of the centerings, however, was similar to that which has elsewhere been remarked upon.

In concluding this section, I may draw attention to a plan of centerings which was adopted by Lieutenant Fraser, of the Engineers, when building the arches (25 feet span) of the Jaoli and Chitowra Falls. The position of the bays at these works, as will be observed by referring to the plan, is most exceedingly awkward for the establishment of earthen centerings, unless they are increased in extent beyond the usual limit. The locality also is especially inconvenient for the subsequent removal of the earth, and the cost attending upon the whole of the operation is very great. During the construction of works of this sort, lime-burning (in which oopla or cakes of cow-dung is the fuel used) was in progress; wood of all the smaller descriptions, such as kurries, tors, and bullas, was also at hand. Lieutenant Fraser, without cutting up any of the wood specifically for the purpose, used it in conjunction with brick and mud supports, for a superstructure of *oopla*, laid closely together, and formed on its upper surface in the shape of the required curve. Upon this as a centering perfect success attended the erection of the arches, which were completed very satisfactorily. Here the cost of the centering was merely the labour of building and pulling down, and both the wood and oopla were uninjured and available for their proper purposes. I consider this to have been one of the best of many applications of simple means to useful purposes that have been exhibited on these works. Although in none of the centerings that were used, even in cases where the haunches were loaded previously to their removal, did we escape from settlement, it was more prominently shown in arches that were built with the plain earth centerings as described under the head of Class II. A. In these cases the separation assumed the character of an absolute fissure on the extrados, until the keying of the arch partially obliterated

it. Of the timber centerings described in this section, I should give a preference to Captain Goodwyn's, Class I. D, on account of its aptitude and convenience in use; to Captain Yule's, Class I. B., for its economy of timber work. The former, being of timbers cut up for the especial purpose, are expensive in manufacture; in use they are economical, as the pieces are placed in position separately. The latter, as I have before explained, are made of the uncut kurri, or staple rafter of the country, which is purchased at a small cost, and is available for its original purposes after the centerings are no longer required; they are not so convenient as Captain Goodwyn's, from their having to be placed in position in masses.

Of the centerings placed under Class II., B is undoubtedly the best, in defiance of its being composed of a mixture of rigid and compressible matter; but in using it, the centering must be removed with as little loss of time as possible, so as to prevent its want of homogeneousness from acting prejudicially to the uniform settlement of the arch.

Before commencing on the subject of the second section of this chapter, it will be convenient to make a few introductory remarks on the general plan of construction in the building of the bridges.

The works of this description, as designed for the Ganges Canal, are built entirely of masonry. In the Khadir, or in the tract above Roorkee, bricks and boulders (or stones selected from the beds of the rivers connected with the mountains), the former predominating, have been universally used, with a cement made of the best species of lime, obtained from the calcination of crystallized limestone collected in the beds of the rivers in the Deyra Doon, and in those of the Ganges and its branches. In the bridges below Roorkee, and

as far down as the 95th mile, brick is the staple commodity; below this point, both brick and block kunkur have entered largely into the construction of all the works, in many of which brick has only been used in the arches. The mortar from Roorkee downwards has been made of a great variety of marles and kunkurs; near Roorkee, and within a moderate distance from the Khadir, the use of the stone lime to which I have referred was extended as far as economy would permit. Marles, some of them of a very superior quality, especially that from Jussooe, then took the place of stone lime; after which, and throughout the whole of the districts of Bolundshuhur, Alligurh, Mynpoori, Cawnpoor, Etawah, &c., lime made either from kunkur gravel, or from that species of material in some form or other, was the staple ingredient for the cement.

The bricks which have been made in our own manufactories for the purpose of bridge building are of the following dimensions:—

$$12'' \times 6'' \times 3''$$
$$12'' \times 6'' \times 2\tfrac{1}{2}''$$

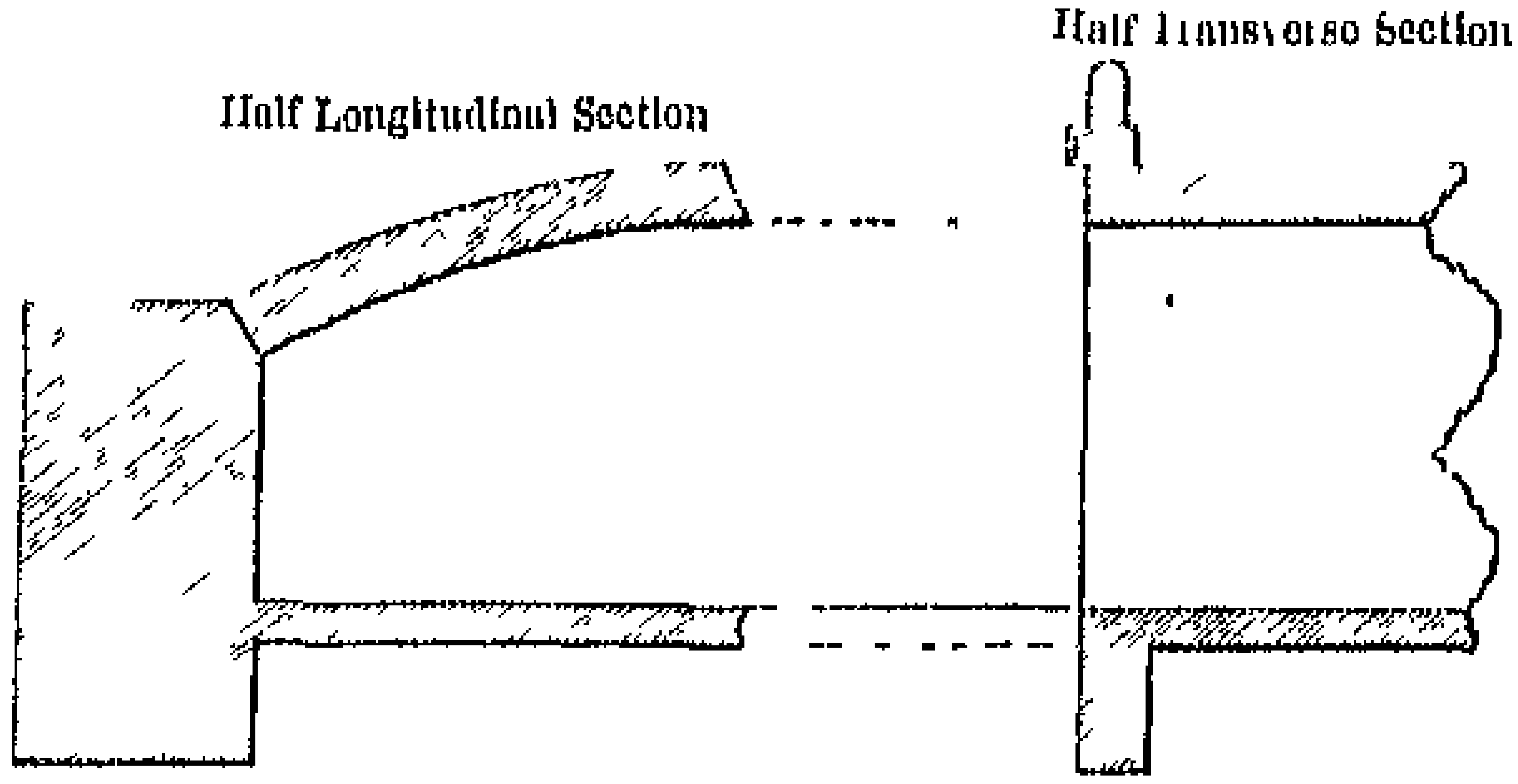
The best are those from the kilns in the neighbourhood of Sirdhanna; they are generally good, however, throughout the upper districts as far down as the Nanoon Regulators: below that point the soil becomes affected by (*reh*) an alkali that appears to deteriorate the earth for brick-making. This reh is not universal, but its prevalence leads to the necessity of great discrimination in the selection of ground for brick manufacture; it has led to much disappointment and much pecuniary loss. As a rule, I consider that the bricks used in the works below Nanoon are inferior to those of the upper districts, and in the Cawnpoor terminal line, that both the bricks and cement which have been used are inferior to others. In the town of Cawnpoor

itself, and in the buildings which are included under the head of the Terminal Works, experience and observation on the inferiority of the material used elsewhere have led to a great improvement in both the quality of the brick and of the mortar, a change which I consider to be due in the latter article to relinquishing, as far as it was possible, any dependence on purchase of lime from contractors, and to seeing that the lime when taken from the kiln was properly separated from the ashes of the fuel (cow-dung) with which it was burnt.

In the design and construction of bridges, I was guided by the following general rules, the leading one of which may be best explained by a diagram :—

1st. All bridges to have floorings with curtains on the waterways, not only for the purpose of adding strength to the work, but to act as a bar for retaining the levels of the canal; the section, longitudinal and transverse, being on the following design :—

Diagram 115



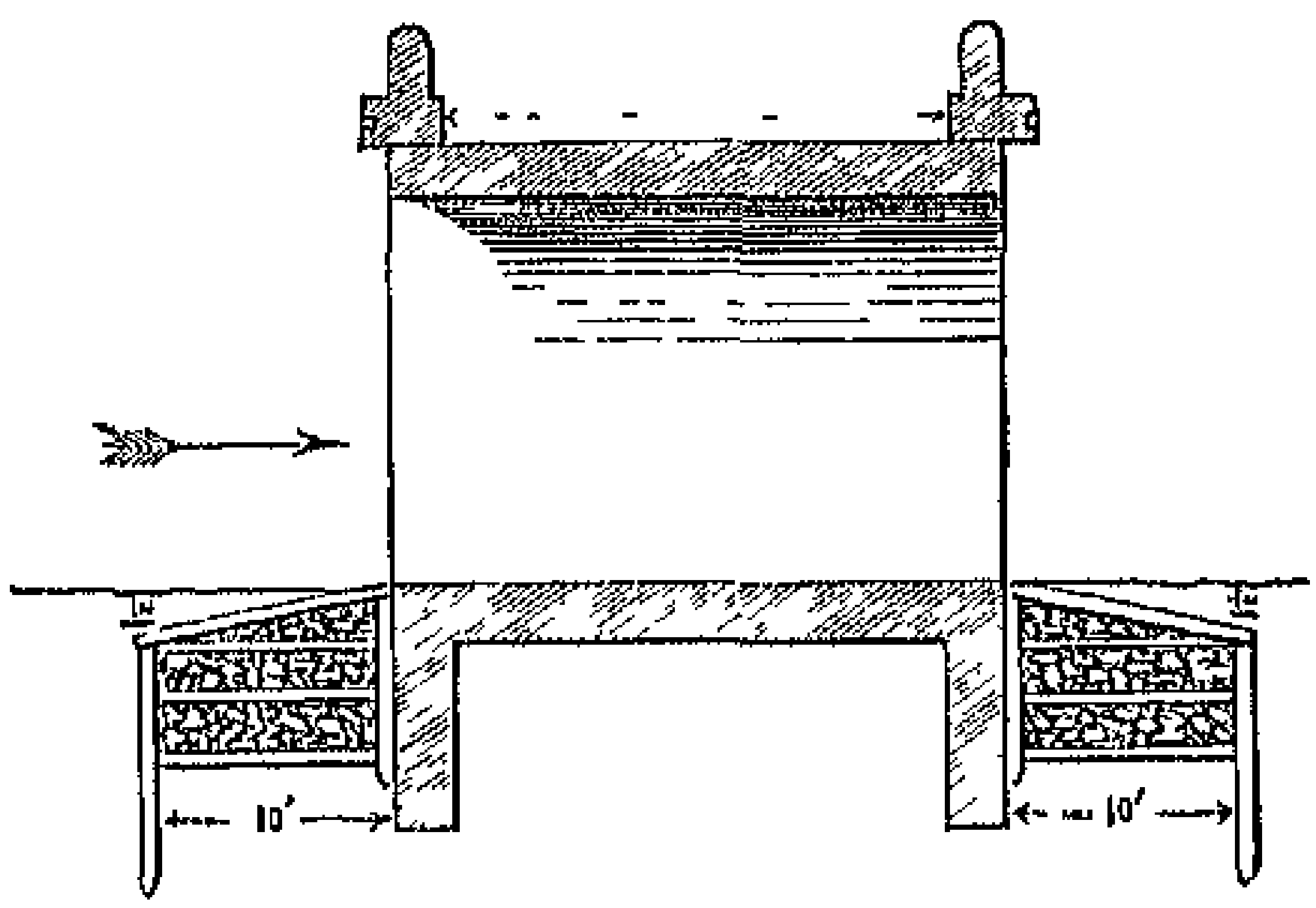
In every case, therefore, there are three elements opposed to the thrust of the arch :—

1st. The abutments and their back soil.
2nd. The masonry wing walls of approach.
3rd. The floorings and curtains of the bays.

2ndly. In all cases where the soil in which the foundations were laid was sand, specific instructions were to be laid down. In common cases, where the ground was hard and of a tenacious quality, the piers and curtains were never to exceed 10, nor be less than 4 feet in depth, the maximum measurement being only necessary in the leading 100 miles of the course of the main trunk line.

3rdly. Where the canal bed in the vicinity of a bridge was sand, or of a light soil, the floorings were to be protected by a line of sheet piling, with heavy material laid in frame boxes, agreeably to the standard plan adopted in the canal works of these provinces, the form of this protective covering being as follows :—

Diagram 116.



The flanks of the canal on its meeting a bridge of this description were also to be protected by piling.

4thly. As a general rule, arches of 60 degrees were to be preferred.

5thly. The roadways were to be perfectly horizontal, and to be constructed on widths adapted to the particular purpose of the line of communication, *e.g.* :—

High military roads	to be	25	feet	in width.
District and police roads	„	20		„
Village	„	„	18		„

These measurements were to be the clear widths between the plinths of parapet walls, or between the brackets figured in diagram 116.

6thly. The drainage of all bridge roadways to be effected through the crowns of the arches by vertical cylindrical holes.

7thly. As a general rule, bridges to be built at every three miles in length of the main canal and its branches; deviations from this rule to be made the subject of specific reference.

The above are the leading points upon which the whole of the bridges have been executed; deviations have in many cases taken place, from causes which will be explained under the details of the individual works; generally speaking, however, the above seven rules may be considered as those which have been our guide in the prosecution of all works connected with cross-communication.

It will be understood from what has been said in former chapters, that the floorings and curtains attached to the bays of bridges are leading elements in the design for retaining the slopes of the canal bed: they were universally adopted in the Eastern Jumna Canal, and may be considered as the salvation of the bed of that work, from the effects of retrogression of levels, arising from extraordinary slopes: their value as retaining bars is beyond all price. In the construction of bridges, however, they have other functions not less worthy of consideration than their influence in checking the action of the current on the bed of the canal. They provide a resisting medium to the thrust of the arch as exerted through the abutment, the strength of which is in direct proportion to their own inertia and capacity to resist compression. That such a medium is an important element of stability, will be at once apparent when it is

borne in mind, that provided the abutment be of good masonry, and thus virtually rigid, the value of the thrust against the floorings and curtains is in the direct ratio of the perpendicular depth, from the impost block to the fulcrum supplied by the floorings referred to.

In further illustration of rule 1 and to the diagram appended thereunto, I will here introduce two other diagrams representing longitudinal sections, where the bridge waterways are flanked by towing-path passages:—

Diagram 117.

Fig 1

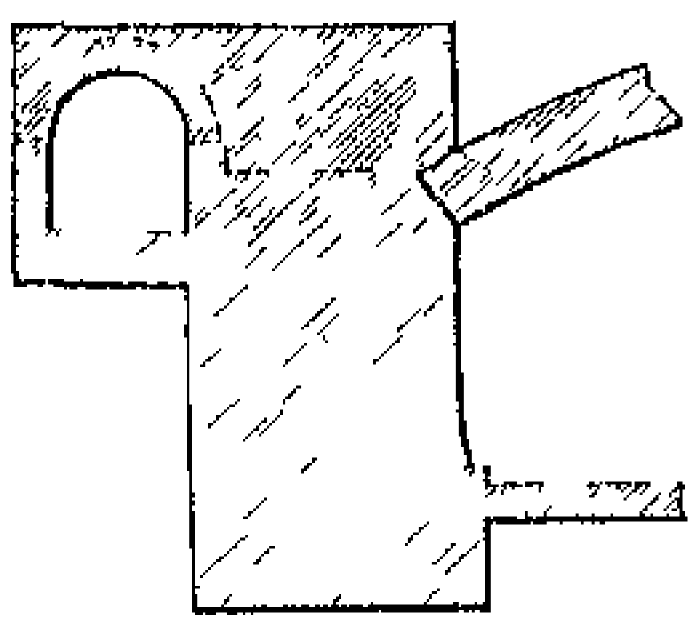
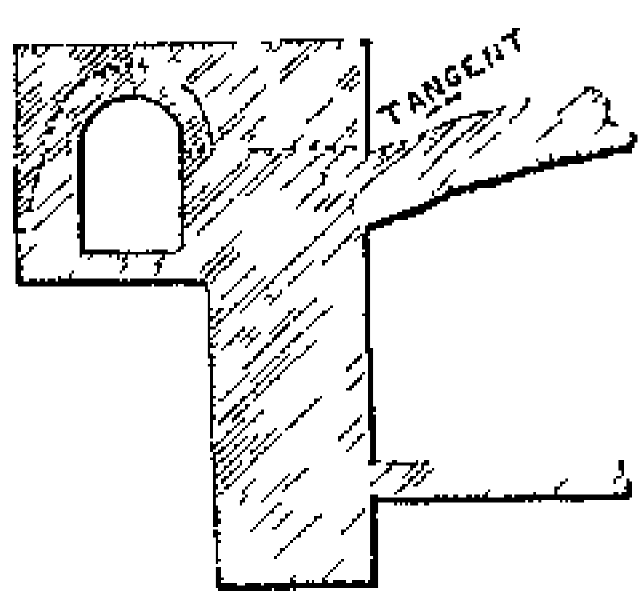


Fig. 2.



Now, to give the fullest benefit to the rules of construction laid down in the above paragraph, it is *evident that before the arch is allowed to exert its action* in thrust, the three elements of design must be complete; that is to say, in the case shown in diagram 115 the bridge floorings must be built, the abutment must rest fairly and directly upon the virgin soil, and the wings of approach must be completed up to the height of the extrados; in the case represented in diagram 117, fig. 2, that in addition to the requirements above stated, the block through which the towing-path passage is perforated must be completed in all its parts; finally, that the whole of the masonry ought to be perfectly indurated. With the material which has been used on these works, a rigid attention to the above rules must inevitably have led to the most satisfactory results.

The two leading elements, viz., the conjunction of the virgin soil with the abutment, and the completion of the wings up to a certain height, were easy of accomplishment, although not necessarily gained in works *carried on at a distance from the executive officer*, and under the management of native mistries, or careless overseers; the third, however, or that appertaining to the floorings and curtains, was, from causes which I will explain, necessarily carried out very imperfectly, and, in fact, to the fullest extent not carried out at all, excepting in those cases where timber centerings were used.

In the construction of all arches with a span exceeding 25 feet in width, it was my original intention to have used timber centerings; circumstances, however, connected with both economy of time and expenditure of money, rendered the scheme impracticable; in building the bridges on the high land below Roorkee, the great expense that would have been incurred by multiplying the centerings required for so many bridges was a consideration of no mean importance; and the delay in completing so many arches with a limited number of centerings would have been fatal to the desired progress of the work. On the other hand, the *adoption of earth* centerings simplified the whole proceeding; it at once reduced the expense, and instantly threw over the line of works unimpeded activity. This activity of progress has enabled us, not only to bring to completion works which certainly could not have otherwise been built in the time to which I felt myself restricted, but in the lower divisions, where the scarcity of material has driven us to all sorts of expedients to reduce the cubic content of masonry, the adoption of the earthen centering has enabled us to vary the width of span, and to reduce it to a minimum adapted to the capacity of channel over which the bridge is constructed.

With the exception, therefore, of the few bridges which have been built in the Khadir, including Roorkee, *and of the six leading bridges on the high land of the* Doab, every work of this sort, as described in the present chapter, has had its arches built on centerings made either of earth alone, or of a combination of earth and brickwork. As I have devoted the leading section of this chapter to centerings, I need say nothing further here, than that by adopting the cheaper and more expeditious plan offered by earthen centerings, we were prevented from building the floorings simultaneously with the piers and abutments, and have, consequently, in such cases, failed in completing the necessary elements required in rule 1.

It will be observed in the section on Centerings, that where the soil was of a good and tenacious quality, the *piers and abutments were built up to the terreplein or* natural surface; the intermediate ground, or that occupying the site of the bay, being left in its virgin state to act as a support for the segmental superstructure required for building the arch upon. Until the arch was built, therefore, and until the time for removal of the centering had arrived, the ground occupying the bay had literally not been touched by a spade; it necessarily followed that the floorings and curtains of which the substructure consisted were, instead of being the first, the last portion of the building executed.

Again in sandy tracts where it was necessary to remove all the soil, and in laying the foundations to great depths, to excavate with wide and extended slopes; where, in fact, the whole of the foundations were laid in a crater, which was, after the completion of the walls, filled in with loose sand; although the curtain walls were built, it was not thought advisable to complete the floorings, until the subsoil was sufficiently compressed. The

floorings, therefore, were delayed until the earthen centerings were removed, and until the thrust of the arch had been brought to act upon the abutments; in this case, however, the third element, although not complete in all its parts, was present in the curtains or lines of foundation wall which give the tie or bond between the up- and down-stream sides of the substructure; it was incomplete solely in the flooring itself. It will be understood, therefore, that timber centerings have been confined entirely, either to the works in the Ganges Khadir, or to the few bridges in its immediate neighbourhood, whilst by far the greater proportion of the bridge arches have been built, either with centerings of earth, or of a combination of material of which earth is the predominating ingredient.

The second and third rules have been, I believe, in all cases implicitly followed. In the Khadir bridges, of which there are only two that come specifically under the present description, the Kunkhul bridge is laid in boulders to a depth of 8 feet, and that at Jowallapoor in a mixed soil to a depth of 8½ feet; in both these cases the third rule for protecting the head and tail has been rigidly attended to. In the high land from Roorkee downwards, as far as the 110th mile, including the bridge at Raoli, the bridge foundations vary in depth agreeably to the nature of the soil. In the Muzuffurnuggur district, for instance, where sand largely predominates, the depth of foundations is never less than 10 feet; that of the works connected with the falls, it will be recollected, is in one case equal to 32·5 feet; in all these cases, however, the floorings are well protected. The soil below the Muzuffurnuggur district, and in the upper part of that of Meerut, is of a better quality; in the latitude of Meerut, we get into the region of spring-water, and into depths of foundations depend-

ing thereupon. From the Raoli bridge and throughout the Bolundshuhur and Alligurh districts, the inferiority of the soil (in many places, at a small depth below the canal bed, pure sand) has not forced upon us the necessity of maximum depths of foundations; but in all doubtful cases, and wherever there appeared to be a probability of current action near the bridge floorings, these portions of the works have been most carefully protected.

On the terminal lines, the soil almost universally is hard and tenacious; the depth of the foundations in no case exceeds six feet, and generally it is only four; the excellence and hardness of the soil have, moreover (in the difficulties under which the executives laboured in procuring material for building), in many cases led to the whole of the superstructure being built on a platform of masonry equal in thickness to that of the floorings, the foundation or curtain walls on the up- and down-stream sides being alone sunk to the standard depth. On these lines, also, protective aprons are given on the rule prescribed in all cases where such appear to be necessary. *As a further guard against accident, and* that we may anticipate, rather than be unprovided on emergency, every bridge, in fact, every masonry work, connected with the canal channel, is supplied with a magazine of heavy material, either in the shape of boulders, blocks of kunkur, or, in their absence, of cubes of masonry. At each of the bridges on the Ganges Canal works, 10,000 maunds, or 350 tons, of this species of material are present on the spot, to secure an immediate remedy in case of accident.

The fourth rule, which prescribes a particular form of arch, has generally been adopted. Even in cases where the elevation is elliptical, the construction is on

a simple segment, equal to one-sixth of the circle; in most cases the segment is externally shown; it enables us to give excess of height to the piers, and thereby to offer facilities for the passage of boats at high water. To the builder and accountant, moreover, it simplifies calculations of cubic content. The only deviation from the 60° arch is in a set of bridges built with small brick, and in some of the smaller arched bridges in the Cawnpoor terminal line, which will be described in their proper place; the increase of rise and the expanse of spandril gained by the shorter radius having, in my opinion, no great beauty to recommend them.

Rule 5 has been acted up to in all cases, and I wish that many of the bridges, in anticipation of the lines with which they are connected becoming "high military roads," had been designed accordingly. In the upper parts of the canal, where the width of channel is equal to nearly 200 feet, a roadway contracted to a width of 18 feet is exceedingly inconvenient, whereas in the narrower parts of the canal such a width of roadway would be sufficient for all practical purposes; to lay down a general rule, therefore, for width of roadways on bridges built under different circumstances was somewhat inconvenient; although in doing so, economy in cost was consulted, as an additional foot even in width would have added largely to the estimate. In the district of Cawnpoor, where the bridges which cross the canal consist of one and two arches only, and the maximum width of the canal channel at its intersection does not exceed 70 feet, the bridge roadways have been made on a width of 15 feet only; but it cannot be too often explained, that the extraordinary and unusual difficulties in procuring material of all sorts (especially brick) in the Cawnpoor terminal line from the 100th mile downwards, led to the reduction of the dimen-

sions of all works to limits which may be considered extreme.

With regard to drainage, the plan laid down in rule 6 has been in all cases adopted, by perforating cylindrical holes of four inches in diameter through the crowns of the arches on both sides of the roadway; this gives a very efficient relief, even in the heaviest falls of rain to which we are subjected.

Very considerable modifications have been made in the seventh rule, which, as is implied, was more intended as a general one for guidance than for adoption in its strictest sense; practically speaking, village roads have been, as far as such could be managed with propriety, limited to distances of three miles apart; but in all cases where the cross-communication of the country would have been in the slightest degree interrupted by such an arrangement, it has been freely deviated from; this is more remarkably shown in the proximity of towns and in the richly-cultivated districts lying below the Nanoon regulators; but even in the main trunk line, where the extent of works for cross-communication, and their cost, naturally called for a judicious, although restricted disposition of works of this sort, bridges have been built at all points where such were absolutely necessary, without reference to the especial rule on which I am now remarking. In looking at the map, it will be observed, that the longest tracts of the canal unbridged exist in the Saharunpoor and Muzuffurnuggur districts, between Roorkee and the Muhmoodpoor Falls in one case, and between the latter work and the falls at Chitowra in the other: the apparent deficiency of bridges in this neighbourhood arises more from their distribution than otherwise. The country above Chitowra is very imperfectly cultivated; it is, generally speaking, much elevated, sandy, and in its present state adapted

to the growth of rain or *khurreef* crops only: this is remarkably shown in the Muzuffurnuggur district, but it is more or less common to the whole tract. In building our bridges, therefore, their sites were determined at points most convenient to the towns and villages in the neighbourhood; in some cases, it will be observed, at distances apart from each other considerably less than that laid down for our guidance. In the Muzuffurnuggur tract the disposition of these works is adapted, in my opinion, to meet even future wants; that in the Saharunpoor district, where the cultivation is of a better description, may be improved by additional bridges built at points equidistantly between the Roorkee aqueduct and the Assoffnuggur falls, and between the Liburheri bridge and the falls at Muhmoodpoor. At both these points my estimate of 1850 included the abutments of suspension or lattice bridges; an idea which has been extended by building the substructure and abutments on the same design as that of the masonry bridges already constructed, viz., of three bays of 55 feet each, with piers of 7 feet in width, giving a space between the flanks or side abutments of 179 feet. To these works floorings and curtains have been added, so that we have the means ultimately of completing them as arched structures, a plan that I strongly recommend. We at the same time have, by this arrangement, added to the canal bed two more retaining bars for the maintenance of the slopes.

In fixing the sites of bridges for high military and district roads, every attention has been paid to the wishes of the local committees in whose hands the funds for road-making purposes are placed; on the other hand, the committees have in all cases responded to the wishes of the director of the works, in connecting the cross and village roads with those bearing upon the bridges; in making roads to meet the bridge approaches where such

did not exist before; and in giving to intermediate estates, or to those whose boundaries lie equidistantly between two bridges, free and open communication with their approaches. A great deal of this most useful and necessary part of the undertaking has been completed, or is in progress at the present time; it is in full vigour in the Muzzuffurnuggur, Meerut, Bolundshuhur, Etawah, and Alligurh districts, in which both the civil authorities and the road committees have been as anxious to give the means, as the canal executive officers have been to carry out the works. It is most backward in the Saharunpoor district, although in the early years of the progress of the works, a good deal has been done in the neighbourhood of Joyallapoor and Hurdwar. From Roorkee to the southern limit of the district, which includes the Assoffnuggur, Munglour, Liburheri, and Muhmoodpoor Fall bridges, no work of the nature alluded to has been yet commenced; the bridges, therefore, are isolated, and are only useful to those whose estates impinge on the track that leads to them.

The design of the bridges has been regulated by two considerations somewhat antagonistic in their requirements; viz.: the necessity for giving a sufficient height to the intrados above high-water mark, to admit of the free passage of craft, and at the same time an equal necessity for placing the roadway at a moderate height above the level of the country, so that the ramps of approach may not be inconveniently elevated.

These two requirements have, as it were, given two parallel lines, separated by a minimum height to which the elevation has been necessarily restricted.

In cases where the depth of section was great, the distance between high-water mark and the top of the embankments was sufficient to obviate any difficulty arising from the causes above mentioned, and in such

cases, elliptical arches have been almost universally used. Elsewhere, however, space has been gained by raising the height of the piers and adopting a flat segmental arch, by which as much freedom as possible is given to the passage of boats on the whole width of the waterway. Passages for the convenience of access to the different parts of the building, both in connection with towing-path purposes and irrigation, have been considered a necessary part of the design, which in elevation has been made as simple as possible, and limited to as few varieties as the nature of the works would admit of. Omitting the bridge at Peeran Kulleeur, which, from its position and height of roadway from the bed of the canal, required a specific design; and that at Sirdhunna, which, from local courses, is also exceptional, the whole of the bridges may be separated into five classes, and placed under the following denominations, viz. :—

1st Class. Elliptical arches with niched pilasters, *vide* pattern Plate XLIX. Atlas.

2nd Class. Segmental arches, with niched pilasters, *vide* pattern Plate L. Atlas.

3rd Class. Segmental arches, with open arched spandrils, *vide* pattern Plate LI. Atlas.

4th Class. Segmental arches, with spandrils pierced by cylinders, and with the towing-path passages marked by rusticated pilasters; *vide* pattern, Plate LII. Atlas.

5th Class. Segmental arches, plain, *vide* pattern, Plate LIII. Atlas.

To these numbers I shall refer in the detail of the different works; noting opposite each any deviation that may occur from the specification above mentioned. To commence, therefore, with—

II. *Bridges between the head of the Canal and Roorkee.*

The greater proportion of the bridges which are built in the Ganges Khadir are connected with the Myapoor and Dhunowri dams, and with the works attached to the Solani Aqueduct. There are only three which fall specifically under the head of the present chapter, and which as being disconnected with the great works above mentioned, and having no connection with regulating either supply or escape, may be classed as works of communication merely. The three bridges which fall under this denomination, are—

1st. The Kunkhul Bridge.
2nd. The Jowallapoor Bridge.
3rd. The Peeran Kulleeur Bridge.

The Kunkhul and Jowallapoor bridges are of the first class; their position is opposite to the towns from which they take their names, and they are provided with roadways of 18 feet in width. These bridges have three bays of 55 feet each, with intermediate piers of 7 feet. The roadways are in both cases elevated 24 feet above the bay floorings, the latter being protected by piling and boulder work. The up-stream and down-stream flanks are covered by flights of steps or ghats for the convenience of travellers.

The ghats attached to the Jowallapoor Bridge are designated the "Dalhousie Ghats," in honour of the Governor-General, by whose orders they were constructed on the application of the inhabitants of the town when his lordship inspected the works in December, 1851. To the left up-stream flank of the Jowallapoor Bridge, the navigable channel head is attached. With the exception of the foundations, and the massive parts of the abut-

ments, the whole of these works are built with brick masonry, with an external coating of stucco.

Timber centerings on the plan shown in Plate LXII. Sheet 2 of the Atlas, were used in the construction of the arches; and the cement used was as follows:—

1 part stone lime.
1 „ soorkee.
1 „ sand.

The quantity of material used, and the rates of building are shown in the following table:—

Bricks, 12″ × 6″ × 2½″	1,055,396
Do. 12″ × 6″ × 2″	265,702
Boulders	120,819 maunds.
Stone Lime	56,174 cubic feet.
Soorkee	63,687 Do.

	RS.	A.	P.	
Masonry of all sorts .	15	8	6	per 100 cubic feet.
Plaster	7	6	10	per 100 superficial feet.

The total cost of each of these works is shown by the following detail:—

	RS.	A.	P.
Kunkhul Bridge . .	25,853	6	3
Jowallapoor Bridge .	39,242	9	11

They were built by Mr. Kay, Assistant Engineer of the works.

The Peeran Kulleeur Bridge is for the passage of the high road between Saharunpoor and Hurdwar; it is situated near a Durgah and Muhummudan shrine, where there is an annual fair at which a large concourse of people is assembled. From the circumstance of the canal channel at its point of intersection by the bridge being of extraordinary depth, it was necessary to vary the design accordingly; its proximity to one of the leading places of assemblage on the route to Hurdwar also, and the necessity for providing wide towing-path passages on the lower levels for the use of the railway between Roorkee and the Dhunowri works, led to further deviations from

the standard plan of bridge that was proposed for the Khadir works.

The plan, sections, &c., of the Peeran Kulleeur Bridge are figured in Sheet XXVI. of the Atlas; its waterway is similar to the bridges at Kunkhul and Jowallapoor, viz., three bays of 55 feet in width, with piers of 8 feet. The arches are segmental (60°), supported on rusticated pedestals, terminated by a flat pyramid, the side of which meets a "corne de vache," or bevel to the face of the arch. The side towing-paths or railway passages are 12 feet in width, and 15·77 feet high from the roadway to the soffit of a flat segmental arch which covers them. These passages are flanked by rusticated work carried to the height of the piers with which they architecturally correspond. A plain shield is placed over the arch of each of these passages. Above this is a simple block cornice, or double lines corresponding in character with the rusticated pedestals, the whole being crowned by a plain parapet wall. The height from the flooring of the bays to the bridge roadway is equal to 36¼ feet. On the down-stream flanks of the bridge, flights of steps lead to the berm, from whence there are ghats for bathing purposes. On the up-stream side, the bridge flanks are protected by wings.

Spring-water, which at the site of the above bridge existed on a level 12 feet *above* the bed of the canal, and which after the channel was opened interfered greatly with excavation in the canal bed, led to a necessity for block sinking for the foundations of the piers and abutments. The blocks for this purpose were undersunk to a depth of 10 feet, and the substructure connected with them was arranged on the usual plan. The floorings of the bays were laid in to a depth of 2 feet with up and down-stream curtains, equal to 10 feet in depth. Both the floorings above described, and the flanks

of the bridge, as well as the fronts of the lines of ghats, are protected by aprons of piling and boxwork. The exterior of this building is stuccoed.

Although segmental, the arches correspond so far with the elliptical curve of those before explained, that with a slight alteration at the haunches, the timber centerings which were in use in the Khadir works continued their services at the Pooran Kulleeur Bridge.

Brick masonry was alone used in this building, with mortar of the following proportions :—

1 part stone lime.
2 parts soorkee.

The quantity of material expended, and the rates of the work were :—

Bricks, 12″ × 6″ × 2½″ . . .	756,800
Bricks, English Machine . .	285,090
Stone Lime	17,242 cubic feet.
Soorkee	34,892 . Do.

	RS.	A.	P.	
Masonry, plain . .	19	5	9	per 100 cubic feet.
Masonry, arch . .	32	14	5	per 100 Do.

The cost, including both bridge and ghats, amounted to Co.'s rupees 35,307-14-0; it was built by Mr. Parker, the assistant engineer attached to the aqueduct works.

Although the three bridges above described are placed by themselves in the present chapter, it must be borne in mind that those which are included in the great works attached to the Khadir, are equally efficient for the purposes of cross communication. The line of canal included in the present section is 19 miles in length; in which, independently of the super-passages for the Ranipoor and Puttri Torrents, which, when floods are not running, offer the freest possible passage for the herds of cattle which graze in their neighbourhood, there are, besides the three bridges above enumerated,—

1 Regulating Bridge at Myapoor.
1 Bridge at No. 2 Falls.
1 Bridge at No. 3 Falls.
1 Cross Bridge at the Rutmoo Works.
1 Regulating Bridge at the Rutmoo Works.
2 Bridges at the Solani Aqueduct;

so that there are no less than 10 bridges, besides the super-passages, making a total of 12 lines of cross-communication over the canal channel in a length of 19 miles.

III. *Bridges between Roorkee and the Nanoon Fork.*

On this line, which constitutes the main trunk of the canal in its progress from Roorkee where it enters the high land of the Doab, to the Nanoon Regulators, at which point the trunk is separated into two branches, the bridges, with one exception, are on the uniform design of the four leading classes, under which they may be placed numerically in the following order:—

1st Class.	7 bridges with 3 spans of 55 feet each.
2nd Class.	14 bridges with 3 spans of 45 feet each.
	8 bridges with 3 spans of 40 feet each.
3rd Class.	5 bridges with 3 spans of 55 feet each.
4th Class.	10 bridges with 3 spans of 50 feet each.
	1 bridge supernumerary at Sirdhunna.

The design for the first class has been described in the former section under the head of the Kunkhul and Jowallapoor bridges, which are patterns for the works now under description: they have towing-paths attached to the left flank of the left bay; consisting of a timber platform supported on uprights which cause no impediment to the free passage of the water through the bay. The waterway and the height of the bridge road from the bed of the canal are similar to those in the Khadir, with

the exception of the bridge at Munglour, where the latter is 25·75 feet. At the village of Mundowli, or equidistantly between the Liburheri Bridge and the Muhmoodpoor Falls, and at Gunespoor, south of Roorkee, the substructure and abutments on class No. 1 have been built, as I have before explained, for ultimate purposes, to be completed as arched bridges.

The soil on all the country as far as the 110th mile, is of a very loose and sandy description, which has led to the necessity of protective measures being taken for the preservation of the floorings and flank of the bridges. At those of Munglour, Liburheri, Dimat, Jansut, Khutowli, Sirdhunna, Nanoon, Moradnuggur, and Peepulhera, ghats have been constructed, which, whilst providing the means of access to the water, gave good protection to the channel on its approach to the bridges. The Khutowli Bridge, which lies at the 62nd mile, and is similar in design to that at Munglour, Liburheri, and others of class No. 1, has a roadway of 24 feet in width, to adapt it to the purposes of the high military road between Meerut and Saharunpoor, to which it affords a passage over the canal. Ghats and means of approach to the water are here designed on a more elaborate scale than elsewhere; they are situated on the down-stream side of the bridge, to which they are attached, whilst the up-stream side is protected in the usual way by flank curved revetments. For a detail of the different bridges, with the works attached to them, reference can be made to Part II., in the second section of the second chapter, of which a full description is given; and there appears to be no necessity to encumber the text with a detail of material and rates of each work, when the whole can be found by turning to the table J in the Appendix. It will be sufficient in this place to note, that the bridges under No. 1 Class, which are included in this section, are built of

brick masonry, with cement made of lime and Soorkhi (pounded brick); that they are all stuccoed externally, and that the roadways are metalled with kunkur. Their approaches from the country are by ramps or inclined roadways laid out on a slope of one in fifty.

The average rates per 100 cubic feet of brick masonry on the above works may be estimated at Co.'s Rs. 14-7-1; and the average cost of a bridge without ghats, at Co.'s Rs. 23,124-10-8.

The depths at which the foundations of the different bridges were laid, will be seen by reference to Plate XLIX. of the Atlas.

Amongst the bridges which come under the second class, are those extending from Peepulhera at the 106½, to that at Sheka, at the 177½ mile; the whole of the bridges from the 106½ mile to the termination of the main trunk, being built on the same general design.

With the exception of the bridges at Peepulhera, Raoli, Dumkowra, and Uchuhja, they are connected with the heads of rajbuhas and inlets, as shown in Plate L. of the Atlas. In the exceptional cases, wings and short lines of ghats are attached, either to the up or down-stream faces of the work, and in some cases to both.

There are two descriptions of waterways: viz., one having 3 bays of 45 feet each, of which the bridges from Peepulhera to Suhenda are examples, the other having three bays of 40 feet each in width: of the former there are fourteen bridges, of the latter there are eight.

These bridges have in all cases their waterways flanked by side arched passages 5 feet in width, pierced through the wings, in prolongation of the towing paths, by which an uninterrupted passage is maintained along the berm. Connected with the heads of rajbuhas which lie on the up-stream side, are lines of ghats with a platform and retaining wall, for the purpose of giving access

to the water; of giving free space for the apparatus required for regulating the rajbuha head supply, and also for protecting the rajbuha head from inconveniences which would inevitably arise, were it in close proximity to the earthwork. At the bridges of Wullipoora, Moondakhera, and Kasimpoor, over which the great roads of the country cross the line of canal, these ghats are extended to a length of 350 feet, bearing upon the bridge flanks in an ogee curve, and approached from the higher levels of the roadway embankments by flights of steps. The berm platform is reached by steps appended to the wing-walls of the bridges, similar steps being provided at the inlet and rajbuha escape. On the down-stream side, the bridge is usually terminated by plain curved revetments, sweeping into the earthwork. In some particular cases, however, at the Dumkowra and Uchuhja bridges, for instance, flights of steps or ghats, giving access to the water from the berm levels, have been added, offering additional facilities for approach to the canal stream. In all cases where such has appeared to be necessary, protective aprons to the walls lying in contact with the current have been adopted; in the Bolundshuhur and Alligurh districts, where block kunkur is abundant, this species of material has been substituted for the piling and box-work, which is used in the northern districts.

The facilities with which block kunkur has been procured at all points through which this series of bridges extends, have led to its adoption to a very great extent for building purposes: with the exception of archwork, nearly the whole of the bridges now under description are built entirely of kunkur; and in the case of the Kasimpoor Bridge, the external faces of the arches themselves are made of this material.

The design of elevation differs in no respect from that which I have placed in No. 1 Class, excepting in having

a segmental, instead of an elliptical arch, and in having a curved batter to the perpendicular faces of the piers, abutments, retaining-walls, &c. From the reduced depth of the canal section, and the height from the roadway to the bay flooring being only 19½ instead of 24 feet, the proportions of these bridges are better than those of the works in the upper district: there is greater harmony between the parts, and their general outline is more agreeable to the eye, than the more elevated structure, buried, as it were, between enormous embankments. Where brick has been used, as in the arch work, and occasionally in other parts of the building, the material has been burnt at our own manufactories, in the puzawa, or native brick-kiln; the size of brick being 12″×6″×3″, and its quality excellent.

A detail of all these works, with their appended ghats, &c., will be found in the Second Part; and that of the material expended, rates, &c., of each separate bridge form part of a table in Appendix J, which is especially drawn up for the purpose of giving the fullest information on the subject.

The description of Class No. 2, requires no further illustration than that the exterior of the bridges is stuccoed, and that the cement used consists of—

1 part of kunkur lime to
1–20th of white stone lime.

The roads of approach, both from the country and from the canal embankments, are laid down on an uniform slope of 1 foot in 50, excepting on the grand trunk road, where this has been diminished to 1 in 100 feet: the roads are metalled with kunkur, and where the ramps of approach are much elevated, their sides are turfed, or in other words, planted with Doob grass.

The average rates per 100 cubic feet, on which the

bridges of this class have been constructed, may be estimated as follows:—

	RS.	A.	P.
Arch-Masonry, per 100 cubic feet . . .	14	9	0
Other Do. " " . . .	11	0	8
Plastering, per 100 square feet . . .	2	3	4

and the average cost of the bridges at—

RS.	A.	P.	
10,920	10	1	each for 135 feet waterway.
10,504	14	1	each for 120 feet waterway.

The depths at which the foundations of the different bridges are laid are exhibited in Plate L. sheet 3 of the Atlas.

Of Class No. 3, there are five bridges only, and these are entirely confined to the line of canal lying between the Futtigurh branch-head, and the town of Sirdhunna, or more properly, between the 53rd and the 71st miles, at which points the bridges of Dukheri and Uturna, both of which belong to the above class, constitute the two extremes of the series. The design was dependent on the material, which consisted of small bricks varying in size from $4'' \times 3'' \times 1\frac{1}{2}''$ to $7'' \times 3\frac{1}{2}'' \times 1\frac{1}{2}''$, procured from numerous old ruins purchased in the neighbourhood, the most prolific source being an extensive quadrangle or surai at the town of Chitowra. These ruins consisted of the small brick above adverted to cemented with mud, an ingredient difficult to get rid of when applying the brick to the new work, and which, undoubtedly, might have been dispensed with with great advantage: the bricks, however, were washed and cleaned before they were placed in the works; and whatever might have been their defects, they were of the greatest aid in accelerating progress. To meet the material in question, it was considered necessary to extend the segment of the arches beyond the standard limit of 60°, as it was supposed that, with an

increased versed sine or rise, there was less risk of failure from the contingency of bad bricklaying. The versed sine, therefore, was increased (from 1-7th of the span, or that, nearly, which is due to an arc of 60° to 2-11ths) to a height of 10 feet. The expanse of spandril caused by the rise of segment, was broken by a series of arches perforated through the bridge, and occupying the whole space bounded by the extrados of the arches, and the line of cornice. The parapets were in open railwork, the diameter of the pillars corresponding with that of the small brick with which we had to deal. Towing-path passages six feet in width were designed on each flank of the main arches, their approaches being covered by curved revetments, or, as in the case of the Jansut Bridge, by lines of ghat. The bridge-wings are fitted with steps on their concave or outward side, for the convenience of descent from the roadway to the towing-path levels. The bay floorings and the flanks were protected by piling and apron work, where such has been considered necessary, and nothing has been neglected to render the substructure secure from the effects of the current.

The roadways of the third-class bridges are elevated 24½ feet above the bay floorings; they are metalled with kunkur, and drained by vertical holes through the crowns of the arches. The ramps of approach from the country are made on the usual slope of one in fifty.

A detail of all these works will be found in the table in Appendix J, before referred to, which will give all the necessary items of expenditure and rates. The cement consisted of—

2 parts earth lime,
1 part soorkee;

and the bridges are externally stuccoed.

On an average, the rates per 100 cubic feet are equal to Co.'s Rs. 12-15-3, and the average cost per bridge,

without ghats, may be estimated at Co.'s rupees 18,636-3-8.

The depths of the foundation are shown in Plate LI. of the Atlas.

Of Class 4, there are ten bridges; extending from the 77th to the 103rd mile, or from the Nanoon Bridge, or that below Sirdhunna, to the bridge of Noorpoor, a village situated below the high military road connecting Meerut and Delhi. The waterway of these bridges is divided into three bays of 50 feet each in width, separated by piers of 6½ feet. The arches are 60° segments. The spandrils are perforated by cylinders which pass through the work, their up and down-stream fronts being finished by a coped or bevelled facing. The cutwaters, which terminate at the spring of the arch, are plain segments meeting in a point towards the stream. The faces of the bridge are quite plain. On each flank, and in prolongation of the towing-path, is a passage six feet in width, maintaining a free line of communication along the berm: these passages are flanked by rusticated pilasters. The wing-walls of the bridge, or those which open out towards the country, are fitted with flights of steps to give access to the berm from the top of the embankments. The whole is crowned by a cornice and parapet on the usual standard dimensions. Plans and sections of No. 4 class bridge will be found in Plate LII. of the Atlas.

As a detailed description of these works, showing the precise nature of their appendages in the way of ghats and flanking defences, is given in the Second Part, and as the table in Appendix gives full information on material, I need only remark in this place, that the same attention that has been given elsewhere in the protection of floorings and sides, wherever the bed of the canal was of a nature requiring such protection, has been given with an unsparing hand to these works. At the Moradnuggur

Bridge, which is situated on the high road between Meerut and Delhi, a series of ghats similar to those which have been built at Khutowli, have been attached to the down-stream side of the work; to the upper side protection has been afforded, as at Khutowli, by wing revetments.

The foundations and the nature of the soil in which they were laid, will be understood by reference to plan No. LII. Spring-water was frequently met with on this line of works at moderate depths.

The roadways of approach, as explained before, rise gradually from the surface of the country to the levels of the bridge road on a slope equal to 1 in 50, the bridge road itself being metalled with kunkur. Drainage is here, as elsewhere, obtained by holes through the crowns of the arches. The height of the bridge road from the flooring of the bay is 19·75 feet.

The works included in this class are entirely built of brick masonry, the cement which was used being either of kunkur lime alone, or earth lime mixed with soorkee in the following proportions:—

2 parts earth lime.
1 part soorkee (pounded brick).

They are stuccoed externally, agreeably to the usual practice on these works.

The average rate per 100 cubic feet of brick masonry, may be considered as Rs. 12-9-8, and the average cost of each bridge, without ghats, as Rs. 14,403-12-4.

The only work that remains to be described, on the section extending from Roorkee to the Nanoon regulators, is the Sirdhunna Bridge, which like that at Peeran Kulleeur, described in Section I., is a solitary exception from the standards enumerated under the five classes. This bridge is on the high road between the towns of Meerut and Sirdhunna; the waterway consists of three bays of 55 feet

each in width; its arches are elliptical. On each flank of the bays are towing-path passages 6 feet in width, the floors of which, being raised above the towing-path, are reached by steps; the design is, in fact, a composite one, the body of the work resembling, in all respects, No. 1 class, the flank passages being similar to No. 5. From its position relatively to the town of Sirdhunna, ghats similar to those at Khutowli and Moradnuggur, have been attached to its down-stream face; to the above two bridges it assimilates also in its up-stream flank protections, and to those of the floorings. With the exception of towing-path passages, the whole work is a close *representation of that at Khutowli.*

In the finish of approaches, roadways and all minor points in external appearance, this work corresponds with those above described. Its foundations are limited in depth to the spring-water surface, which lies at a depth of 6 feet below the bed of the canal; they are protected both on the up and down-stream faces by a double line of piles; the intermediate spaces being filled with large masses of block kunkur. The flooring of the bridge is protected both on its up-stream and down-stream face by aprons 20 feet in width, extending from one side of the channel to the other.

The Sirdhunna Bridge is built with brick and lime cement, consisting of the following ingredients:—

2 parts earth lime,
1 part soorkee;

and it is externally stuccoed.

The rate per 100 cubic feet of masonry, is on an average of the whole work, Co.'s Rs. 13-5-5, and the total cost of the bridge was Co.'s Rs. 31,571-12-0.

In the section which I have just described, and which embraces a series of works on a line of 161 miles, we

have independently of the bridges above enumerated, which amount to 45—

> 10 falls, the heads of which are crossed by bridges,
> 4 regulating bridges at the heads of branches;

giving a total of 59 points at which the canal may be crossed by the public. In addition to this, preparatory measures have been taken (by laying in the substructure previously to the admission of water) for the building of two more bridges at the villages of Mundowli and Gunespoor. With 59 bridges, however, on the above distance of 161 miles, we obtain an average of 2·72 miles between each bridge, which, by completing those at Mundowli and Gunespoor will be diminished to 2·63. With roads well laid out, and brought to bear upon the bridge approaches, by lines radiating from the villages and estates lying intermediately between the bridges; and in cases where estates are inconveniently separated with the aid of the civil authorities in making equitable adjustments in the land so separated, the number of bridges now built will, I doubt not, be sufficient for a long time to come.

IV. *Bridges on the Terminal Lines between the Nanoon Fork and the Ganges and Jumna.*

This section includes the whole of the bridges which lie between the Nanoon Regulators and the heads of the terminal works, *i.e.*, in the case of the Cawnpoor terminal line to the Dubowli Escape, in that of the Etawah line to the escape at Moosanuggur, with very slight modifications, and those only in a few instances, to which I shall draw especial notice. The whole of these works belong to the fifth class; the whole of them, moreover, would have been on one regular graduated system of waterway (*i.e.*, no arches exceeding 33 feet in width, none less than 20),

had circumstances arising from difficulties in procuring material in the Cawnpoor terminal line, not interrupted it. *I may observe, however, that throughout the whole* of the works, the design of inlet and rajbuha channels, with ghat facings, is, with very few exceptions, universal; the few cases in which these appendages have not been built are consequent on the inapplicability of the site for the purpose. It will be understood, moreover, that the rules for bridge building, which I have explained in the early part of this chapter, were here, as elsewhere, in full force. With these few remarks I commence with—

A. Cawnpoor Line.

From Nanoon to the Dubowli Escape, which lies at the head of the Cawnpoor terminal works, and to which point the bridges to be here described are limited, the distance is 165 miles; the rectangular section of the canal channel varies from a maximum of 80 to a minimum of 20 feet in width. The design for waterways upon which the bridges were commenced was as follows:—

From	1st to 30th	mile,	3	bays of	33	feet each.
"	30th to 50th	"	3	"	30	"
"	50th to 70th	"	3	"	26	"
"	70th to 85th	"	2	"	33	"
"	85th to 120th	"	2	"	30	"
"	120th to 140th	"	2	"	25	"
"	140th to 150th	"	1	"	30	"
"	150th to 165th	"	1	"	25	"

giving an equal series of dimensions, so that the native mistries might after building one bridge be at no loss in completing the others. I have elsewhere described the cause which led to an alteration in the above arrangement, and which forced us, even at the expense of additional labour to the superintendent, to enter into a more minute graduation of the waterways, thereby

reducing the cubic content of each work, and the quantity of material. The dimensions of the waterways on the revised plan have been shown in the Second Part, when describing the progressive development of the project.

Although differing in width of span of arch, the bridges are all on one design, with the exception of three of the single arched bridges on the up-stream side of Dubowli, a description of which will be given presently. They consist of plain 60° segmental arches, supported on piers both with and without batter, the cutwaters terminating at the spring of the arches: these cutwaters are finished by a cornice which encircles the pier, and from above which the spring of the arch commences; the tops of the cutwaters on the up and down-stream sides are crowned by an elliptically sloped dome. On each flank are towing-path passages 4 feet in width. The wings of approach are on their concave or external side fitted with steps for the convenience of access to the berm levels. In all other respects the face of the bridge is quite plain, topped by a cornice and parapet of as few parts as possible, and in every case the roadway, and consequently the lining out of the courses, is perfectly horizontal.

In cases where rajbuhas and inlets are attached to the bridge, the design is precisely the same as that explained in the second section. The ramps of approach are on a slope of 1 in 50, excepting at the crossing of the Grand Trunk Road and its branches, at which points this has been reduced to 1 in 100. In minor details one general design has been pursued in all these works: differences in the parapets and cornices being the only deviations from a strict uniformity.

The soil throughout the Cawnpoor terminal line is good for foundations: in very few places have we come in

contact with sand, and generally speaking the virgin earth is as hard and compact as it could well be. Beds of kunkur in block or in tabular masses have (strange to say from its abundance in the neighbourhood) seldom been met with; but in the form of loose gravel it is universally found, either in beds or scattered indiscriminately through the soil. Superficial efflorescences of soda are characteristics of all this part of the country; the alkali is, as I have before said, very injurious to brick-making, and I may remark in passing, to brick or kunkur structures which are raised in connexion with it. The nature of the earth in which the foundations have been laid, has led to great variety in their depths; the curtain walls, or those stretched across the channel and forming the up and down-stream sides of the bridge foundations, have in all cases been carried to the standard depth; the cross walls, or those on which the piers and abutments rest, have frequently, when the soil was good, been omitted, the superstructure being raised on a massive flooring, extending over the whole surface from the back of one abutment to that of the other, and in frequent cases between the 100th and 165th miles, the counterforts in rear of the abutment walls, or the supports upon which the towing-path passages rest elsewhere, have been omitted. For plans and sections of these foundations, see Plate LIII. of the Atlas.

The material used has depended entirely upon the resources of the officer engaged in any particular part of the line; in some cases kunkur has been the sole material, in others brick; whereas it has been by no means uncommon to use both brick and kunkur in combination. At the villages of Husseyrun, Bahosi, Goonaha, Oomurda, and Juggutpoor, the arches of the bridges are built of kunkur, which at this point is of a very superior quality, free from the honeycombed texture which is the charac-

teristic of the kunkur formation, and quite as compact as many of the newer limestones. As a general rule, however, the arches, the largest of which has a span of 35 feet, are built of brick. The cement consists principally of—

3-5ths kunkur lime,
2-5ths soorkee or bujree;

the detail of which, together with the amount of material, &c., will be found in the table in Appendix J.

The average rates have been as follow:—

	RS	A.	P.
Arch masonry, per 100 cubic feet . .	21	8	6
Plain masonry, per 100 „ „ . .	14	7	9
Plastering, per 100 superficial feet . .	3	1	9

And the average cost per bridge may be estimated at—

	RS.	A.	P.
For 3 arches each, 33 feet span . .	11,025	13	2
„ 3 „ 32 „ . .	10,935	1	5
„ 3 „ 31 „ . .	10,081	8	0
„ 3 „ 30 „ . .	10,050	5	7
„ 3 „ 29 „ . .	9,932	15	4
„ 3 „ 28 „ . .	9,891	12	11
„ 3 „ 26 „ . .	9,859	15	0
„ 2 „ 35 „ . .	9,514	7	5
„ 2 „ 33 „ . .	9,656	13	5
„ 2 „ 32 „ . .	9,583	5	1
„ 2 „ 30 „ . .	8,747	12	4
„ 2 „ 25 „ . .	7,721	0	0

The old road between Mynpoorie and Agra crossed the canal at an angle of 65 degrees its alignement was very irregular; and although metalled and raised sufficiently above the country, was open to much improvement. I had in all cases avoided skew bridges, in consequence of the great additional expense that they would lead to, as well as that the only legitimate excuse for departing from the rectangle is where the crossing occurs in the midst of towns, or land of a very valuable description which would be injured by an alteration of approach; or, in cases where the facilities of thoroughfare would be materially benefited. As neither of these desiderata existed at the

crossing above alluded to, the Dunahar Bridge has been constructed at right angles to the axis of the canal, and the approaches have been brought to bear upon it in sweeps, as shown in the plan of this particular work, the whole of the approaches have been laid out with great care under the eye of the executive engineer, and I do not anticipate any objections to the omission of the skew.

The average rates per 100 cubic feet at the Dunahar Bridge are :—

	RS.	A.	P.	
Plain masonry . .	15	4	5	per 100 cubic feet.
Arch masonry . .	21	14	0	per 100 " "
Plaster . . .	2	10	4	per 100 superficial feet.

And the total cost of the work is Co.'s rupees 12,419-1-4.

On reaching the 145th mile, the bridges are reduced to waterway of 30 and 25 feet in one segmental arch. Of this description of bridge, there are eight. With the exception of those at Koorsowli, Barah, and Muswanpoor, having pilasters between the towing-path passages and the main arch, they are in design and construction similar to those before described. At the village of Khujoori, where the canal is crossed by the high road between Cawnpoor and Kalpi, the bridge, which is on the last dimension above noted, is built on a skew, with an angle of 37 degrees: the road on its approach to the canal was well lined out, straight, metalled, and of uniform dimensions, the angle of intersection was at the same time moderate: here, therefore, was a case where the skew pattern might be appropriately introduced, and it has been completed very satisfactorily, leaving the original alignement in its former state. The bridge, both up and down-stream, is protected by ghats, with steps of descent from the higher levels of the roadway. The ramps of approach are on a slope of 1 in 100,

and the finishings, both in masonry and earthwork, are of the same description as elsewhere.

These bridges are built entirely of brick with cement consisting of:—

2 parts of kunkur lime,
1 part of soorkee or bujree.

The average rate per 100 cubic feet of masonry may be estimated at:—

	RS.	A.	P.	
For arch work . .	19	12	3	per 100 cubic feet.
For plain work . .	13	12	6	per 100 " "
For plastering . .	3	4	6	per 100 s. feet.

The cost of each of the plain single arched bridges was on an average equal to Co.'s rupees 6,844-12-4, that of the skewed bridge at Khujoori was Co.'s rupees 9,341-10-6.

On the Cawnpoor terminal line from the head at Nanoon to the Dubowli Escape, which, as I have before said, is 165 miles in length, there are 57 points at which the canal can be crossed by the public, the average distance between each bridge being 2·89 miles. This, with a proper adjustment of roads (the position of the bridges having been determined with reference to straight lines drawn between the leading towns in the districts), and especially by the radiation of village tracks towards the main roads of approach, ought to throw the whole country open, and render the means of cross communication sufficient for all practical purposes.

B. Etawah Line.

From the Nanoon Regulators to the Moosanuggur Escape, between which the bridges in this section are limited, the distance is 170 miles. The channel is very similar in capacity, and the design for the bridges varies in no great degree from that which was laid down on the Cawnpoor line. Here, however, the resources of the

country have enabled us to maintain our bridges on the original scale, and to construct them with the fullest liberality of material. At the period that I am writing, I may, however, observe that the works have not been advanced farther than the 110th mile, and therefore, that the districts parallel to those in which the executive engineer of the Cawnpoor line had so much difficulty in procuring labourers and materials, have not yet been reached. Lieutenant Whiting, the executive engineer of the works, does not, however, anticipate the difficulties or want of resources met with in the Cawnpoor terminal line, and there is little probability, therefore, of our being prevented from completing the bridges as they were originally designed. These bridges are as follow :—

From	1st to 10th mile,	3	bays of	33	feet each.
„	10th to 30th	„	3	„	30	„
„	30th to 50th	„	3	„	26	„
„	50th to 70th	„	2	„	33	„
„	70th to 90th	„	2	„	30	„
„	90th to 110th	„	2	„	26	„
„	110th to 130th	„	1	„	33	„
„	130th to 150th	„	1	„	30	„
„	150th to 175th	„	1	„	26	„

The design of the whole corresponding with that under the fifth class, with the exception of the single arched pilastered bridges, which lie on the up-stream side of the Moosanuggur Escape.

The detail of all these bridges, noting the extent of ghats and appendages to each, has been before given in the second part of this paper; and the rates and detail of material used will be found in the table in Appendix J. The average rate per 100 cubic feet of brick masonry may be estimated at rupees 12-5-9, and that of kunkur at rupees 11-12-0, and the average cost of bridges as follows :—

	RS.	A.	P.
3 arches of 33 feet each . .	10,892	9	8
3 „ 30 „ . .	10,121	4	4
3 „ 26 „ . .	9,143	6	9

The nature of the soil on the country through which the Etawah line runs, is very similar to that which I have described in the former section; it has all the advantages of tenacity and retentiveness, and all its evils of local admixture with soda. As a rule, however, it is well adapted for foundations, and for the sustaining of abutments or retaining walls, when such walls are placed in contact with the virgin soil. The material both in brick and lime, and the method of using both, either mixed or separately, are common to both the Etawah and Cawnpoor lines; and as the standard rules for construction are the same in both, there appears to be no necessity for repeating what has been already said in a former section.

We have within the limits of our present detail, a number of bridges equal to 40, scattered over a line of 110 miles in length, giving between each bridge an average distance of 2·75 miles. The same remark which I made on the subject of roads, applies here as it did elsewhere. The only way that the bridges can be turned to proper account is by opening lines of approach to them; the funds for doing this are in the hands of the civil authorities, and of the local road committees, each or both of whom will receive the most ready aid from the canal authorities, if they please to take advantage of it. At the time that I am now writing, considerable progress has been made in lining out and constructing roads connecting the bridges on the Etawah and Cawnpoor terminal lines, most of which have been completed between the Nanoon head and the high road between Agra and Mynpoori. I am greatly indebted to the exertions of Lieutenant Whiting of the engineers, the executive engineer of the Etawah terminal line, for the great progress that has been made in road-making in the districts connected with his works.

V. *Bridges on the Branches.*

This section includes the bridges on the Futtigurh, Bolundshuhur and Kool branches; works which from causes before explained, have, up to the period at which I am now writing, been only partially proceeded with. With the exception, in fact, of initiatory surveys, the completion of the leading six miles of the Bolundshuhur Branch, arrangements for material in the early part of the Futtigurh and Bolundshuhur branches, and the completion of the works at the heads, nothing has been done. In the design of the bridges, however, I have no idea of deviating from that which has been put in practice on the main trunk line. The plan of combining with the bridges the different works for inlet and outlet appears to have great advantages, in both compactness of design, convenience of supervision, and in affording drainage to the bridges in the neighbourhood of the approaches, which must necessarily be much elevated. The flat segmental arches, by admitting of increased rise to the height of the piers, give facilities to the transit of boats and rafts, whilst they secure to the roadway the smallest possible rise above the level of the country.

The width and capacity generally of the rajbuha heads might be retained at the minimum measurement, used on the main trunk line, viz., with a width of 6 feet; that of the inlets I would retain on the standard measurement, which gives space for the introduction of labourers for the purpose of clearance. The length of ghats or face for giving protection to the head of the rajbuha, and the retaining wall in its rear, might be very much reduced, the former to a mere platform sufficient for working purposes, the latter altogether; steps of descent being constructed (as has usually been done elsewhere) on the concave surface of the wing walls. Unless experience

points out that the position of the rajbuha head and channel thus designed is inconvenient, and liable to interruption from silt and sand deposits, the modified design for the branch bridges as above suggested will, I think, be a good one, and at the same time moderate in cost.

Under the above explanation, and in the order of precedence in which the branches are situated on the main works, I would for the Futtigurh Branch adopt the following design for waterways :—

	Width of excavation Receiving Channel	Bridge Water-way.	How Divided.
	Feet.		
From 1st to the 15th mile	70	75	3 bays of 25 feet each.
" 39th "	65 / 60	60	3 " 20 "
" 69th "	55 / 50	50	2 " 25 "
" 108th "	45 / 40	40	2 " 20 "
" 132nd "	35 / 30	30	2 " 15 "
" 150th "	25 / 20	25	1 " 25 "
" 159th "	...	20	1 " 20 "

On the Bolundshuhur and Kool lines where the width at the head is 50 feet, the table above given would be equally applicable.

For the elevations, Class 5 would be that appropriate to all the bridges with more than one arch. The single arched bridges might be similar to those in the vicinity of the terminal works on the Cawnpoor line, that is to say, with the towing-path passage flanked by pilasters; or, what would be more economical, and perhaps more appropriate to village and country bridges, they might be made perfectly plain like those in Class No. 5 above noted.

It is unnecessary to say anything further on the con-

struction of the above works, as they are copies of those which have been already built, of which plans and all necessary sections are shown in the Atlas.

This chapter would be incomplete were I not to add some concluding remarks on the bridges which have been described in the preceding pages, and which have been completed previously to my resigning the directorship of the works. These remarks will naturally apply to the classes separately, an arrangement that will enable me to bring under review the different works under their exact specification; commencing, therefore, with—

No. I. Class,

the standard design of which is figured in Plate XLIX. of the Atlas.

The bridges under this class are as follow; including those which are attached to the Solani Aqueduct termini:—

1. Kunkhul.
2. Jowallapoor.
3. Muhewur, or up-stream Solani Aqueduct terminus.
4. Roorkee, or down-stream aqueduct terminus.
5. Gunespoor (substructure only).
6. Munglour.
7. Liburheri.
8. Mundowli (substructure only).
9. Dimat.
10. Toghulpoor.
11. Belra.
12. Bhopa.
13. Khutowli.

The Mundowli and Gunespoor works are, as I have

above explained, left in an incomplete state, so that they may hereafter be finished with masonry arches.

The five leading bridges on the list were built under the executive superintendence of Captain Goodwyn of the Engineers, the remainder by Lieutenant Fraser, of the same corps, aided by their assistants. The arch, although with an elliptical outline on its intrados, is, as will be seen by the plan, a segment, the voussoirs being brought to bear on one centre; the impost blocks, or skew-backs on which it rests, are formed by horizontal brickwork, which is projected so as to form the lower portion of the elliptical curve. In one instance only, viz., at the Munglour Bridge, this rule was experimentally departed from, the voussoir in that case being brought to bear upon five centres, and the arch being constructed on an ellipse.

The thickness of arch was 3 feet in all these bridges. With the exception of the arches of the Khutowli Bridge, which were built on centerings made with plain earth, the arches of the above bridges were built on timber ribs resting on cross walls of brick with mud cement.

On my rejoining the works early in 1848, the piers and abutments of the Kunkhul, Jowallapoor, Munglour and Liburheri bridges were completed; timber centerings had been prepared for the arches, and the works in question were in progress of induration. The brick manufactories, which had been since the year 1842 in progress, under interruptions of various kinds, had at this period arrived at a fair state of organization; and from the head works to the town of Sirdhunna, not only had large supplies been collected, but kilns were in progress in sufficient numbers to secure an energetic advancement to the masonry works. The whole of the bridges, therefore, which are included in the present class, were completed without delay.

With the exception of the two bridges which are

attached to the aqueduct, and to the works in the immediate vicinity of Roorkee, none of these bridges have escaped without settlement after the superstructure was built. This was shown by slight openings on the parapets, generally speaking, over the haunches of the arch, not extending below the cornice, and in all cases, even in those of the Munglour and Jowallapoor bridges, where they have appeared most prominently, of very small dimensions. The whole of these bridges, with the exception of those at the aqueduct and at Khutowli, appear to me to have been somewhat hastily stuccoed, the outer coating of this material having been laid on before the arch had permanently settled, and before the masonry had become perfectly indurated.

Having drawn attention to the Jowallapoor and Munglour bridges, I may observe that the defect in the former may be derived from an accident which occurred to the right abutment and wings shortly after the work was finished. During the rains of 1850, flood-water broke into the canal through the embankment at the right down-stream wing, which it carried away. It is possible, that what with the shock of this accident, and what with the torrent of water pouring into the canal at the back of the right abutment, this part of the work suffered. The defects here are merely an extension of the openings to which I have before alluded, the arch itself being intact. The whole has been very well repaired by Mr. Kay, assistant executive engineer attached to the division. In relieving the arches from the centerings, the settlement was considerable, as will be seen on reference to Table I. of the Appendix.

The Munglour Bridge is the only one in which the voussoirs of the arches are directed upon numerous centres; and, whether from this cause or otherwise, the settlement has been more here than elsewhere. The

lowering of the centerings of this bridge which was the first constructed in the second division of the works, was superintended by Mr. Read in person; the result in the case of one of the arches was unsatisfactory; the actual sinking of the crowns on the removal of the centerings was thus:—

Right arch, 3·78″
Centre arch, 3·77″
Left arch, 4·52″.

The two former stood the ordeal well, but on the left for a space of 5 or 6 feet across the arch on the up-stream side, cracks showed themselves of sufficient opening to admit of a flat ruler being pushed in to the depth of 6 or 7 inches; the bricks at the crown and haunches of the up-stream face appeared, too, to have been somewhat disarranged. Both the keying and bricklaying of these arches were carefully looked after; but the executive engineer supposed that some careless brickwork had been introduced, and that in defiance of all supervision, the construction of arches of large dimensions with the inexperienced workmen with whom we had to deal, must in the commencement be liable to annoyances of this sort. This bridge was allowed to stand without stucco for twenty-four months; on the completion of which time, it was concluded that any further settlement was out of the question. Since the completion of the stucco, however, slight openings have appeared in the parapet walls over the haunches; and although there is no reason to apprehend any serious extension to these openings, they disfigure the appearance of the work.

I have, in the leading section of this chapter, when treating of centerings, explained the universal separation that took place on the flanks, generally speaking, from the 6th to the 12th course from the skew-back. With

timber centerings the sixty degree arch that we have used has in *every case* exhibited this peculiar feature. In the earthen centerings, the causes that I have shown for the separation at this particular part of the arch, are more clearly recognizable than those in the case of the timber centerings. In the former the separation distinctly takes place during the building, and when the weight of the arch begins to act upon the compressible material of which the centering is composed; in the latter the separation seldom occurred until the arch was keyed and the centering removed. In Table I., which will be found in Appendix, the amount of settlement on the removal of the centerings is shown of each arch that has been constructed. The action on the haunches, and the amount of settlement are clearly due to the nature of the seams of mortar in voussoir, the necessity of attending to which in its greatest minuteness is a matter of very serious importance. For instance, the length of a segment of a circle of 60 degrees, whose radius is 33·feet is 34·55 feet: in examining this arch I find that the number of courses of 3 inch bricks which have been laid in voussoir is equal to 126; that $126 \times 3 = 378$ inches, or $31\frac{1}{2}$ feet; and that consequently 3·05 feet in length of this arch consists entirely of a soft compressible material. Now, on 127 seams the average width of each on the above results is ·285 inches, whereas the width of seam with mortar as it is commonly ground ought not to exceed ·25 of an inch (properly speaking and with well-cut bricks ·175 might be obtained).

All excess over the minimum dimension above noted may be considered as directly tending to settlement more or less injurious to the arch. In a case that came under my notice, in which the argument held was, that it was better to allow the native misteri to follow his own habits, which were founded on experience, of the value of the

material with which he was working, than to interrupt his progress by the introduction of European systems. A series of arches had been built with excellent 3-inch bricks, and with kunkur lime cement, the latter somewhat coarse, but supposed to be of a good quality for hydraulic purposes. Some of these arches were semicircular, others were flat segments similar to that described above. The seams of cement were in no solitary instance under three-quarters of an inch thick, generally speaking they were above an inch, and they were averaged in my note-book as one-inch seams. The number of 3-inch bricks in an arch of the above dimensions is 100, giving a total length of 25 feet. Of the full arc, therefore, there were in this case no less than 9·55 feet in length of mortar: that is to say, of a matter purely compressible, and directly detrimental to the stability of the arch. I may observe (and this is a fact that was not considered by the builder), that the native mistori never removes his centering until the material of which his arch is composed is perfectly indurated; he never, moreover, dreams of building flat segments, his form of arch being confined to semicircular, pointed, and to the Tudor outline. The value of the semicircular native arch depends upon its massive proportions more than upon its correctness of voussoir, or the equilibrium of its parts. The adaptation, therefore, of the native style of bricklaying to arches subject to our discipline, was altogether inappropriate; and the proof of its being so, was shown in a case where the arch of a towing-path passage which had been built on the native plan, with seams (as after examination showed) of upwards of one inch in thickness, was in the course of a few months utterly destroyed. The passage of carts over this arch, and the vibration attending there-

upon, had so completely disintegrated the mortar, that the bricks actually separated and dropped out, leaving holes through the crown of the arch. I am aware that, with roughly formed bricks it is difficult to obtain seams of the reduced thickness, but it is economy in the end to cut such bricks into shape. I prefer this at any cost, to concentric rings, which is one way of getting out of the difficulty, and which in fact was adopted in the works at Myapoor: but if it is an accepted fact, that no two arches settle equally or uniformly, it follows that if three lines of arches are laid above each other, and are built with the intention of performing the duties of a solid arch, any inequality of settlement of the three concentric layers will defeat the object in view; nor will an occasional bond formed by bricks dovetailed between the rings which I have had pointed out to me on English railway works, as an antidote to the evil of which I complain, act further than in disarranging the equilibrium which really does exist without them. That a reduction in the extent of seams is gained by the concentric layer system, I admit, but its liability to irregular settlement appears to me to render its advantages questionable.

On the Ganges Canal works, the greatest attention has been given to the reduction to a minimum of the seams, both in plain building, as well as archwork, and I would bring forward the whole of the works on the Solani Aqueduct, as well as those in the khadir, as good specimens of close, and, according to my idea, well-laid brick-work. On the whole line of works, in fact, from Myapoor to the Termini, there are few arches that I would not produce as illustrations of excellent brick-laying. The bridges under this class are built entirely with brick.

No. II. CLASS—*The standard of which is figured in Plate L. of the Atlas.*

Those bridges, which are very similar to those above described, and principally differ in their having a segmental instead of an elliptical intrado, are built in one continued series from the 106½ to the 180th mile: they consist of two varieties of waterway, the leading ones having three bays of 45 feet each, and those which are situated below having three bays of 40 feet each.

The works under this class may be thus enumerated:—

Three bays of 45 feet each.

1. Peepulhera	8. Dhumkowra.
2. Raoli.	9. Urrowli.
3. Nidhaoli.	10. Wullipoora.
4. Jarcha.	11. Mamun.
5. Geesoopoor.	12. Uchuhja.
6. Sumowta.	13. Moondakhera.
7. Pukkanna.	14. Suhenda.

Three bays of 40 feet each.

1. Daopoor.	5. Barota.
2. Birowli.	6. Machoon.
3. Dubtulla.	7. Chungeri.
4. Kasimpoor.	8. Shoka.

making a total of twenty-two bridges.

The two leading bridges at Peepulhera and Raoli were built under the supervision of Mr. Read, the executive officer of the Second Division; the whole of the others were laid out and completed by Mr. Volk, the executive officer of the third division of the works. The design is similar to that originally proposed, with modifications adapted to the project of 1850. The introduction

of block kunkur in conjunction with brick, is the most remarkable feature in this class of bridges. Block kunkur, in fact, may be considered the staple material for the whole of the building, with the exception of the arches, which are invariably made of brick; brick, too, is used, generally speaking, in cornices and finishings, but not universally.

The arches of the Peepulhera and Raoli bridges were built on plain earthen centerings, similar to those which, under the section on centerings, I have placed under the denomination of Class II. A. Those from Nidhaoli downwards were built on centerings composed of external ribs of temporary brickwork, with an interior filled with earth, as shown under the head of Class II. B. I have, in its proper place, given my opinion as to the value of these different sorts of centerings. They have, with the exception of the two cases above-mentioned, been universally adopted in the building of the bridges of the second class.

From the nature of the centerings and the rigidity of the external ribs, which prevented the settlement which I have before alluded to, the separation at the haunches, as shown so distinctly during the progress of the building of the arch, was less frequent here than in the cases above described. It was seldom observable until the centerings were entirely removed, and then in a very slight degree. As a rule, however, after the construction of the parapets, and when the arches were loaded to their fullest extent, exceedingly slight openings exhibited themselves in the parapets over that part of the haunches to which I have before alluded. The settlement merely showed that the same action, and the same cause for it existed in these bridges as it did in others.

The use of block kunkur so largely throughout these works, and its satisfactory appearance when the bridges

were completed, rendered it a matter of regret that they should be stuccoed. In cases where mixed material had been used, such a coating was desirable; but in others, as far as mere appearance was concerned, the plain stone buildings would have been a pleasing variety. The texture of kunkur is honeycombed, and as a rule not compact. In extremes, the stone may be described in its most perfect state, as a gray semi-crystalline rock, tough, with occasional amygdaloidal or irregularly shaped hollows, dispersed throughout its mass, the hollows being filled with earth. In its most imperfect state (I allude simply to the block kunkur, which is available for building purposes), these hollows are more numerous, and they give to the rock the honeycombed appearance to which I have before adverted. It is found in extensive tabular masses or strata (generally accompanied by sand), the upper and lower sides of which are slaty and apparently imperfectly indurated; the induration, in fact, increases towards the centre, where it is frequently of the hardest description of the newest lime rocks, and of a crystalline character. In using this material there were a few indispensable rules to be attended to.

1st. The entire removal of the outside or slaty portion.

2nd. The placing of the masses in a horizontal position, and in courses corresponding with their laminæ, or with that in which they lay in the quarry.

3rdly. In using the material at all, the greatest attention to be given by the engineer superintending the works, not only to the efficient quality of the material, but to *seeing* that the two former rules were abided by.

The outside was hewn off by the quarry labourers in some cases, in others at the works themselves. Heavy axes (koolharies) were used for this purpose, and as far as my periodical inspections admit of judging, the first

rule has been strictly attended to; the chips or fragments removed from the blocks in preparing them for the building have been used as metalling on the roadways. As far as such was possible, the second rule was followed, and there is no doubt that the strictest attention was given by the engineers to the quality. After all, however, good as the appearance was of works built with kunkur, it was very evident to me that from the nature of the material, and from its honeycombed texture, its outside surface required protection from the action of running water, as well as from that of weathering. In the former case it was clear that stucco must be used; as the current would in a very short time relieve the hollows from their earthy particles, giving the outside exposed to the action of water a most unsatisfactory, if not dangerous surface. In the latter case, where the work was not exposed to the attrition of water, the very nature of the rock, calcareous and rusticated in surface, laid it particularly open to the effects of weathering, to the reception of seeds and vegetation of all descriptions to which buildings in India are subjected, and to both these evils being considerably magnified by the excess of moisture that will attend upon the introduction of irrigation.

I may observe that, although I had no experience of the effects of attrition of current upon this species of rock, its use in buildings is so common in these provinces, that there can be no mistake about its efficiency in the first place, and the action that weathering exerts upon it in the second. The latter is in direct proportion to the extent of the honeycombed nature of the stone used. Where this is in excess the surface assumes an appearance like that given to rusticated pillars and plinths, where loose bits of gravel have been stuck in mortar. Where the rock is compact and crystalline it withstands the weather as well and better than our freestones and oolites of England; in this

case it is an admirable building stone. Its colour is gray and therefore cold, which in a hot climate and under a broiling sun may be considered rather advantageous than otherwise.

In extensive works, like those with which we were connected, it was impossible to draw very minute distinctions; and in fact, the very superior class of kunkur which I have above described is so rare, that it never existed uniformly in any particular work. It was therefore determined that the whole of the bridges, whether built of kunkur or not, should be stuccoed, and that experimentally the back retaining walls connected with the embankments, which were out of the reach of the canal channel, should be left unplastered, so that hereafter an opinion might be formed as to the advisability or not of leaving kunkur surfaces exposed. All these kunkur works, therefore, as far as they are directly in contact with the water in the canal channel, are stuccoed.*

No. III. Class—*The standard of which is figured in Plate LI. of the Atlas.*

The bridges under this class are five in number; they commence immediately below the head of the Futtehgurh Branch, at the 54th mile; and with the exception of the Khutowli Bridge, continue uninterruptedly to the 72nd: they are called :—

1. Dukheri Bridge.
2. Jansut Bridge.
3. Surai Bridge.
4. Suthori Bridge.
5. Uturna Bridge.

* *Since this was written, many of these bridges have been entirely covered with stucco.*

I have before described that the design of these bridges originated in the necessity for using native bricks of a small size, which were procured from the extensive ruins at Chitowra and other places in the neighbourhood. To meet the insufficiency of this species of material for 60 degree segments, the rise of arch was increased to 10 feet. To break the continuity of the surface given to the spandrils by this excess in the rise, the bridge roadway was supported on an open line of arches resting upon the segments as open ribs spanning the waterways. By this arrangement the superstructure was reduced both in weight and extent. The sides were flanked by towing-path passages.

These arches were built on plain earth centerings, and from the nature of the brick that was used, and the consequent superabundance of cement which it necessitated, the settlement on the removal of the centerings was considerable. Three of these bridges were stuccoed very shortly after the masonry was completed, and subsequent settlement has produced the same disfigurements in the parapet walls as I have mentioned in former cases, where the plastering or stucco was somewhat injudiciously hurried forward. The defect is more conspicuously marked on these bridges, from its appearance on the arches which occupy the spandrils. In portions of these works connected with the wings of approach, and the steps of descent which are attached to them, it was found necessary to substitute the large for the small brick. Proximity of kilns to the Dukheri and Jansut bridges, rendered such an arrangement a matter of no difficulty. I have not been at all satisfied with the results of building with the old bricks. From their small size, and frequently being in fragments, the proportion of cement is extraordinarily great, so that the building in mass consists of mortar, in a proportion that

exceeds all belief. A specimen of a wall which fell during the rains of 1852, presented a most unusual exhibition of this material. In addition to this (in itself a great defect), the ruins which were composed of brick laid in mud, although easily pulled down from the circumstance of the facility with which the bricks were separated, produced a material more or less covered with dirt; and with all the care that was given by the executive officer, no washing could utterly get rid of it. An earthy substance in contact with the brick was destructive to the proper adhesion of the lime cement, and was in itself, therefore, injurious. These two defects, although deteriorating the value of the masonry, and showing that when constructed with the old bricks, it is decidedly inferior to that composed of the new and larger sized kind, are pointed out as the results of our experience on these works. The lime that has been used is derived from a very superior description of marle (called earth lime, to distinguish it from that burnt from kunkur). The bricks with which the arches were built were, I believe, very carefully selected, washed and laid, and as far as quality is concerned, are of the very first description, as all the little bricks used by the natives are. In both these respects, therefore, viz.: in goodness of lime and quality of brick, nothing could be better than the material with which these bridges are built; but their good qualities are neutralized in part by want of bond, excess of mortar, and introduction of foreign matter in the shape of mud into the masonry.

On this subject, I may remark, that the presence of the ruins which provided the works with such an enormous quantity of material has been the main cause of our being able to complete such extensive works in so short a period of time. By singular good fortune, the engineer

might perhaps be excused for saying, by a providential arrangement, these ruins were in the market, on the only part of his district where good brick soil was scarce, and where fuel was (at a reasonable cost) literally not procurable: he found himself in the midst of plenty when on the brink of starvation; and neither he nor I can be much blamed for feeding on manna in the wilderness, although such manna might not have been equal to the things on the rich man's table.

No. IV. Class—*The standard of which is figured in Plate LII. of the Atlas.*

The bridges under this class commence at the 77th mile, from that below Sirdhanna to the Noorpoor Bridge, or that situated at the 103rd mile: they come under the following designation:—

1. Nanoon.	6. Nowari.
2. Jutpoora.	7. Sounda.
3. Pooth.	8. Didowli.
4. Jannikhoord.	9. Moradnuggur.
5. Nugla.	10. Noorpoor.

The buildings have towing-path passages flanked by rusticated pilasters, with the spandrils pierced by cylindrical holes: in other respects they are quite plain. The settlement of the arches which are segments of 60°, and which were constructed on plain earthen centerings, was less here than elsewhere. I believe that the experience gained in building former bridges was partly the cause of this result. At any rate, the delay in completing the superstructure, as well as that of covering the exterior with stucco, has, I have no doubt, been successful in diminishing the disfigurements to which I have before

alluded. In these bridges, however, previously to the building of the parapet walls, the settlement of the haunches showed itself in the crown of the spandril cylinders; the action having resolved itself in these cases into one separation, centrically situated between the two haunches. The separation at this point was exceedingly small; but I draw attention to it, as a proof that settlement at this period of the progress of the building was here, as elsewhere, prevalent. The whole of these works are built of new brick, and they appear to me to be the best constructed bridges in this part of the canal. The brick-laying in the arches was particularly good, and the seams were reduced to a minimum. The span of each arch is 50 feet in width, and the depth or thickness is 2½ feet at the crown, and 3 feet at the impost blocks.

No. V. Class—*The standard of which is figured in Plate LIII. of the Atlas.*

An enumeration of the bridges in this class will be found in the second part of this paper, under the description of the Cawnpoor and Etawah Terminal lines, to which they are entirely confined. They are quite plain, with no other ornament than a cornice round the pier and cutwater heads, and a string course separating the parapet from the face of the building. With two exceptions in the Cawnpoor line, where the span of the bridges has been increased to 35 feet, the maximum span is 33, and the minimum is 25 feet. Kunkur and brick have been used indiscriminately as one or the other was available; the latter being, with the exception of the arches of the Husseyrun, Bahosi, Gonaha, Oomurda, and Juggutpoor bridges, universally applied to the construction of the arches. The whole of

the arches of this class were built on centerings of earth, supported on each side by brick and mud walls on the plan noted as Class II. B. After the removal of the *centerings, the separation which I have before described,* and which, in fact, has universally attended the removal of every centering whether of timber or otherwise, occurred, I believe, in all cases, and always in the same position, that is to say, at a distance of from six to twelve courses of brick from the impost block. Further action appears to have depended greatly on the application of the superstructure.

The instances where arches were built of block kunkur, the stone was of a very superior quality, and well adapted to any species of building. In texture it was compact and crystalline, and with hardly any traces of the earthy concretions, which are so characteristic of the kunkur formation. Here, however, as elsewhere, I have sacrificed the desire that I had for exhibiting this stone as a becoming one for ornamental building, to the fear that was entertained of the joints giving cover to vegetation, and of the surface being injured by the action of the current or disfigured by weathering. These bridges have been coated with stucco, in the same way as those which I have described under the head of class No. 2.

I have a few remarks to make on the bridges, which as not conforming in elevation and design to those legitimately answering to the classes above mentioned, have been separated and placed by themselves. These, as will be understood from what has been before written, consist of the—

1. Cross bridge at the Rutmoo works.
2. Peeran Kulleeur Bridge.
3. Sirdhunna Bridge.

and the single arched bridges lying above the terminal works, which may be thus denominated :—

On the Cawnpoor terminal line—
Koorsowli,
Barra,
Muswanpoor.

The cross bridge at the Rutmoo is in elevation similar in many respects to that of Class No. I. Its arches are elliptical, and described on the same number of centres; but its cutwaters are not surmounted by pilasters. Circular headed niches, however, placed centrically over the cutwaters, and dies sunk in the spandrils, give it an appearance not unlike that of the class before mentioned. The abutments of this bridge are more massive than those of Class No. I. They are connected in their substructure with the under-drainage of the revetments.

The Peeran Kulleeur Bridge, the design of which has been before described, was completed about the time that I left the works: at this period it was without stucco; and although during the construction of the arches, settlement in the usual form had occurred, the external face of the elevation exhibited no trace of it.

The Sirdhunna Bridge, which was one of the earliest that was built, had its superstructure laid on at a period too shortly after the arch was thrown to save the parapets from the action of settlement; it was stuccoed, moreover, immediately after the building was finished. The design differs from that of No. I. Class, merely by the introduction of flank towing-path passages.

On the Cawnpoor line, the bridges included in this list were amongst the first that were built; their completion and stucco were hurried forward; and the result is shown in parapet disfigurements.

The haunches in every case have been marked by a

separation in the voussoir, so exceedingly slight as to be unobservable without close inspection, but still existing in evidence of the action that has taken place. The defect does not appear to depend upon the substructure, but rather on a settlement of the crown of the arch itself. In all bridges without reference to extent of piers or abutments, or to the nature of the soil in which the foundations are laid, and especially where the superstructure over the arch has been hurried to completion, subsequent settlement has, although without any apparent increase to the defect above mentioned, shown itself by an opening of the parapet walls: this also in a very slight degree, the fissure not being traceable in connection with the arch, but clearly, I imagine, depending upon it. I attribute the evil to the use of compressible centerings of the nature described in the leading section of this chapter.

I believe that in practice, where centerings are removed on the plan which I have described, and which is for the purpose of enabling the arch to acquire its proper equilibrium at a period when the cement is moist, and when such moisture admits of the most perfect compressibility, the separation at the haunches is, if not universal, of such frequent occurrence, as to render it a matter of no consideration; the openings, in fact, become immediately closed; and the joints from the settlement of the brickwork, and the softness or moisture of the cement, attain a degree of fineness as also of uniformity, that could not be attained by any other means. It becomes a question, however, in how far such settlement may be due to the yielding of abutments either by their turning on the base as a fulcrum; to the compressibility of the material of which the abutment is built; or finally, to the slipping of the horizontal courses of masonry which form the abutments.

Now, with regard to the first point, or "the actual yielding of the abutment itself," it will be seen by referring to my first rule for bridge building, that the intervention of curtains and floorings to the bays,* prevented the abutment from turning on its fulcrum or base line. Where timber centerings were used, these floorings and curtains were universally built before the arch was relieved from its centerings; in other cases they were absent. Whether, however, they were present or absent the separation at the haunch took place. The action, therefore, on the arch appears to have been uninfluenced by this circumstance. Again, in cases where the extent of the abutment and its excellence of workmanship placed all probability of yielding out of the question, the separation at the haunches seemed to prove indubitably that the action arose simply from the settlement of the crown, and without reference to those parts of the structure on which the arch rested. I have taken much interest in the progress of these buildings, and have lost no opportunity of examining the impression that this action of settlement exerts on the intrados of the arch or on the work generally, by endeavouring to detect cracks or marks of separation on the one, or a want of perpendicularity or disarrangement in the other. As my observations have been especially directed to those bridges where the stucco had been finished, and the surface of which would necessarily exhibit the smallest possible defect, I may

* With the exception of the bridges, which were built at the commencement of the works, viz., those at Kunkhul, Jowallapoor, Munglour, Liburheri, Togulpoor, Dimat, Baiha, and Bhopa, to which either ghats or flanks were subsequently added, the bridge arch abuts centrically upon a long line of wall, which extends to a considerable distance both up and down-stream on each side of the arch. The face of this wall is perfectly smooth and even; so that were the thrust of the arch to affect its abutment, action on the face of the wall would be inevitable, and could not escape detection. In a settlement that took place in the Dhunowri Road Bridge, the settlement was marked by a separation of the wall on the up-stream side, a short way above the

remark that the cases where I have observed traces of action on parts of the building in the region of the skew-backs are exceedingly rare, and of a nature leading to great doubt as to their origin.

In the instances of the Dukheri and Surai bridges, which come under the head of Class III., where the building material is of old native brick, the inside of the towing-path passages next to the waterway showed slight traces of action in a horizontal separation of the plaster at a point just above or corresponding with the extrados of the main arch and its impost block; the separation was sufficiently distinct to attract my attention, but the trace was exceedingly small, and confined to the passage itself. Evidence appeared to be offered here of the thrust of the arch having affected the masonry.

In a case of a single arched bridge of 30 feet span, Class No. V., at the village of Barra, similar horizontal separations took place in both the side passages, extending more or less over the extrados of their arches; in this case the separations were more distinct than in those before described, although they were entirely confined to the region of the passages themselves: here, however, the soffit of the main arch showed a hair line distinguishable on the stucco, distinctly continuous, but not traceable beyond the intrados. Evidence of action was here again manifest, and the trace on the soffit of the main arch was in all probability dependent on the action exhibited on the side passages.

In all these cases the defect may have arisen from the quality of the masonry. The very questionable nature of the cement used at the Barra Bridge, and the unquestionable thickness of the seams, much acted on by

point where the arch abutted on it. In no other case amongst the numerous bridges which have been built on these works has this action been in the slightest degree shown.

salts, appeared to me to account for the separation described at the Barra Bridge.

The soil in which the foundations of the three arched bridges at Dukheri and Surai were laid was sand; that at Barra was sand also. No abutment sinking or disarrangement could have taken place from the reasons stated in the foregoing note; and although it is possible that the centre piers of the three arched bridges may have settled, there is no evidence of such having occurred.

The actual vertical settlement, of the substructure of the bridges extending from Roorkee to the 110th mile, is by no means an impossibility. It universally rests on sand, and in some cases, as it will be observed by reference to the plans, is below the natural spring level surface. Traces of such settlement could not, however, escape detection.

With regard to the second point, or "the compressibility of the material of which the abutments and substructure are composed," in how far the settlement of arches may act on the skew-backs, it is not very easy to decide; but it is clear that compressibility in that region must depend entirely on the nature of the masonry. Where this is of brick compactly laid in with narrow seams and joints of mortar, and allowed perfectly to indurate, the masonry must be proof against any force that arches of our dimensions could exert upon it. On the other hand, when the masonry consists of badly-put-together brickwork, or of kunkur either of inferior quality or of unevenly squared blocks, in which cases the joints are necessarily either large or imperfectly filled with mortar, the compression of the material is by no means an impossibility. If to the above evils, a want of induration is added, the thrust exerted by an arch would inevitably affect the abutment. At one period of

our *bridge building, kunkur was used in the impost* blocks, and the whole thrust of the arch was exerted on masonry made of this material. This was corrected afterwards, and *the best brick masonry was substituted* for that of kunkur; the use of the latter being confined to those parts of the work on which a dead vertical weight was exerted. The change was made from the possibility of kunkur impost blocks being liable to compression from the causes which I have before enumerated; but there is no evidence of their ever having acted injuriously, or of settlement to the arch having taken place from their use.

If the masonry, whether of kunkur or of brick, of the bridges above described, was laid in with all the care that it ought to be, and which, to the best of my belief, it has been in all occasions; compressibility, although sufficiently active on the arch itself on the removal of the centerings, and up to the period of the induration of the cement with which it is built, could not have extraordinary influence on the rest of the building.

The third and final question to be considered is, "the slipping of the horizontal courses of masonry." In the *northern division of the works, where stone lime* and soorkee as a compound are used for the purposes of mortar; and even where the earth lime, which I have elsewhere referred to as of a very superior quality, has taken the place of stone lime; the evil to which I am now addressing myself is one that can hardly be anticipated: certainly only in cases where the thrust of the arch has been brought to bear on an imperfectly indurated mass; and such, from the period to which the substructure has been invariably allowed to stand previously to the fixing of the centerings, has not been the case with the knowledge of the supervising establishment.

In the southern or lower divisions, the lime is not equal in quality to that which is used above; and in some cases, from the coarseness of the ingredients which have been mixed with it, especially the bujree or fine kunkur gravel, the thickness of the seams exposes the courses of brick or kunkur to greater chances of slipping than would have been the case had the mortar been of a fine consistency, or had the seams been thinner. In a case of careless building by a contractor, we had an exhibition of this evil; but with this exception in which the arch fell, as will be described hereafter, no bridge that has been built shows the smallest sign of action from the slipping of the courses of the masonry. I confess, however, that had I been prepared for the thickness of seam that has in some cases shown itself from the use of coarse mortar, I should not have placed the towing-path passage in such close proximity to the waterway. It is from this contingency of bad bricklaying, and not from any objection to the design otherwise, that I have recommended, as a general rule, that the towing-path passage and the waterway of the bridge should be separated by a distance of 2 feet plus the width between the waterway and the point of intersection between a tangent to the extrados of the main arch and the flooring of the passage.

In the construction of the numerous bridges which has taken place during the last six years, under all sorts of contingencies, it is gratifying to find that in two cases only accidents have happened. Both of these cases show, in a remarkable degree, the evils of inattention to the proper use of mortar in seams, and are curiously illustrative of the questions discussed in the foregoing paragraphs. The two exceptions to which I refer took place in the building of the Dimat and the Bhosan bridges; the former under Class I., and situated at the 32nd mile of the main trunk; the latter under

Class V., at the 145th mile of the Cawnpoor Terminal line.

In the first case, the arches, 55 feet span, were built on timber centerings with material of the very best description, and under the eye of an assistant executive officer. The arches were keyed as usual, and the process of striking the centerings commenced. So great was the quantity of mortar used, that the arches literally followed the centerings in their gradual depression; and had the timber work been entirely removed, would have fallen to the ground. This was prevented by their resting on the framework. After the depression had proceeded to an extravagant extent, the masonry was pulled to pieces. At the period when this occurred I was too far off to visit the spot, but I directed the assemblage of engineer officers in committee to report on the causes of failure. The president's report is sufficiently interesting to give it admission into the Appendix, where it will be found marked K.

The results were arrived at without demurrer; the abutments were sound, and not disarranged in the slightest degree. The accident had occurred simply from an over-abundant use of mortar in laying in the courses of brickwork in the arch.

The second example occurred in a small single arched bridge with a span of 30 feet, the only bridge on the Ganges Canal works that had been entrusted by an executive engineer to a contractor. The contractor, however, was overlooked by a native sub-assistant civil engineer. In this case, immediately the centering was removed, the left impost block with its superstructure and towing-path passage in its rear, slipped away, and the arch fell to the ground. This was a direct and unmistakeable case of "slipping of horizontal courses of masonry." The abutment below the slipping surface

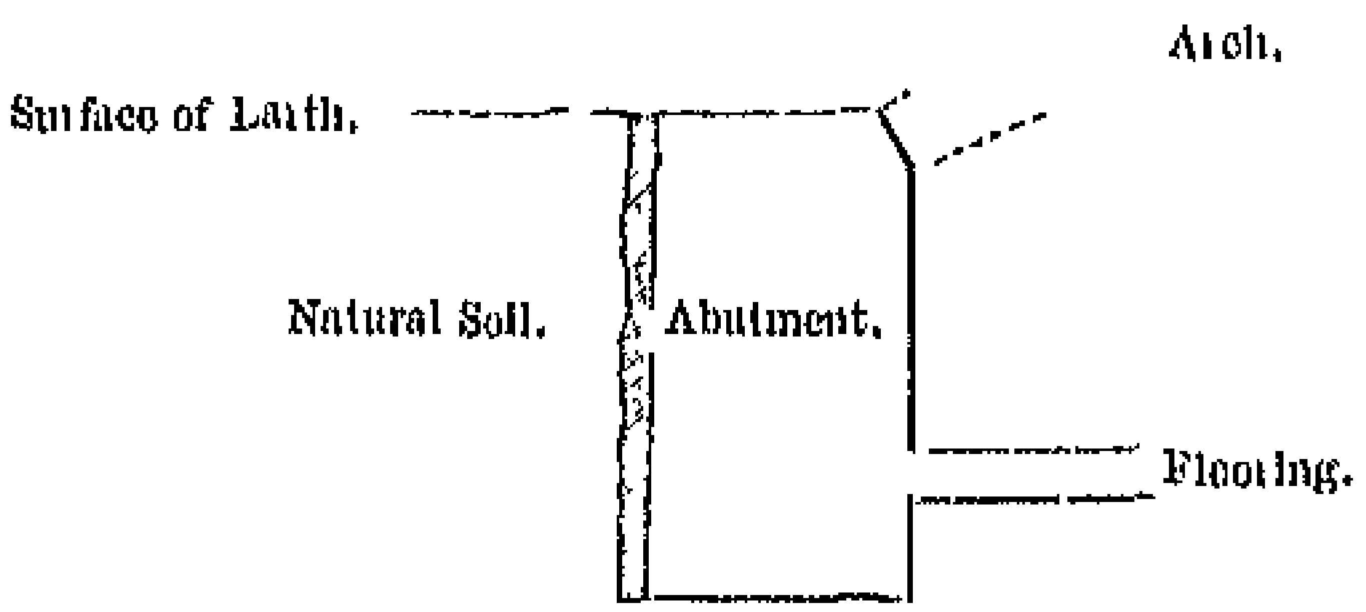
was uninjured, and (as this was an especial part of the inquiry) I may observe that no trace of yielding or action upon it in the slightest degree could be discovered. On examining the causes of this accident, it appeared that that part of the abutment on which the impost block rested, was literally made of rubbish. The executive engineer of the division reported, "The cause, as it appeared to me, of this accident, was solely the very bad quality of the masonry in the backing of the arch, and in the great quantity of mortar used, and in the very inferior quality of this mortar." It appeared that this contractor had only built the arches and skew-backs, the substructure having been completed by the sub-assistant civil engineer. In addition to the contractor's bad work, as leading to the failure above described, the masonry had not been allowed a sufficient time for induration.

The bridge at Bhosan is one of a series built under great difficulties of resources, and a want of material which placed the executive engineer at his wits' end. The abutment walls of the bridge in question have no counterforts in their rear; they rest upon the virgin soil, which in all this part of the canal is of the compact and retentive nature that I have before described it to be. Diagram 117, *fig.* 2, *of this chapter, is* an exact representation of a section of these abutments, showing the position of the towing-path passage, in the present case unsupported by masonry walls, but imbedded in a soil, I should say, as incompressible as masonry.

It is perfectly evident, that the value of this method of construction and design depends entirely upon the abutment being placed in close approximation and in direct contact with the virgin soil; and that if a hair's breadth of space is left between them, the abutment becomes isolated, and is no longer in dependence upon one of its elements of support. Again, in making

excavations for foundation walls, the masonry must rest upon the virgin soil. Excess of excavation refilled by loose earth so as to bring the cubic content of work built on a par with that of the estimate, is, if anything, more dangerous and detrimental to the stability of a structure than that before alluded to. Yet in works under the management of European overseers, I have had repeatedly to notice cases in which both the above errors had been committed. In closing this section, therefore, and in addressing myself to men of the above class, I shall repeat, in the words of one of my circulars: "I would here draw attention to the necessity in excavating foundations, to dig the earth as closely as possible to the true dimensions of either foundation wall, abutment, or retaining wall that comes in contact with it. If a narrow space is left between an abutment and the soil, the former becomes isolated, and derives no sort of benefit from a contact which is intended to be its safeguard. For instance, taking the following diagram of the abutment of a bridge: if the space marked in shade is left

Diagram 118.



hollow, or only loosely filled with earth, the masonry derives no aid whatever from the soil, and the abutment loses all the advantage in its opposition to the thrust of the arch which it ought properly to derive from being backed by a rigid mass. This hollow space ought in no instance to be allowed; and if the excavation is

greater than the width of the abutment, the whole of the space excavated ought to be filled with masonry."

"The same remark applies to depth of excavation for foundations: where this has been carried to excess, the whole *ought to be filled in with masonry; to use loose or imperfectly* rammed earth is tantamount to ruining a building."

"The use of abundance of water in kunkur or brick-laying, is as indispensable to the goodness of work, as thinness of seams of mortar, and thinness of plaster, to its durability."

In concluding this chapter, I may observe that it has been an object in all the designs of bridges, as well as of works in general which are connected with the canal channel, to accompany them by means of access to the water. In cases where revetments are required, such revetments have been commonly designed in the form of ghats. Rajbuha heads are universally protected in front *by lines of this species of stepped revetment,* and to the whole of the bridges, with very few exceptions, ghats or flights of steps have been attached. At those bridges which are crossed by the leading and high military roads of the country, or at those which are situated near large towns, or leading places of resort, very extended lines of ghat have been appended, so that travellers and foreigners who come in contact with the works of the Ganges Canal, may appreciate an undertaking which has been designed for the benefit of the general community, as well as for that of the agricultural population in its neighbourhood. In designing the ghats, whether at bridges or elsewhere, my intention has been to open them to the *free and unimpeded use of all, whether travellers, or* village people, to whom they will offer the greatest of all luxuries in an Indian climate—bathing; and to the Hindoo population the greatest of all possible advantages in this world—access to Gunga Mai.

CHAPTER IV.

WORKS OF ACCOMMODATION.

THE object of these buildings is to provide accommodation to the supervising officers in their progress of inspection, and to the establishment in charge of the works, the watercourse heads, and the irrigation.

They have been designed on plans which are figured in Plates LIV. and LV. of the Atlas, and consist of two species of buildings, which are denominated first and second class "chokies," or in plain English, "station-posts."

The first class chokies have a centre room 20 feet square, with an enclosed veranda round it of 10 feet in width, the veranda being divided off into rooms, *with porches, on two sides which open into the centre,* with which a room on the third side is connected. On the fourth side a separate room is devoted to the accommodation of a subordinate, in the event of the centre room being occupied by the superior officer. The rest of the veranda accommodation is for the purpose of store-rooms and places of residence for the canal native establishment.

The second class chokies are similar buildings, without the veranda, or outer enclosure: their dimensions, properly speaking, were designed at 18 feet square, on which they have generally been built. In some cases, however, this has been reduced to 18′×14′, and in others increased to 20 feet square, the latter in cases where the

attachment of an outer veranda, so as to convert the building into one of the first class, has been contemplated. These buildings are for the residence of the chokidars and native establishment, and for the protection of tools and stores.

The whole of these buildings, whether first or second class, have flat roofs; the object having been to avoid, as far as possible, the contingencies of fire, to which thatched roofs are liable. They are, with few exceptions, built of refuse material; that is to say, of the half burnt bricks which remain in kilns after the works directly connected with the canal channel had been completed. The cementing ingredient is mud. Both externally and internally, however, they are stuccoed or plastered with lime cement. In the language of the department of public works in these provinces, they are built of "kucha pukka," brick and mud, the brick being what is called "peela," or half burned.

Their position relatively to the works is uniform; this is on the left or roadway bank, on the up-stream side of bridges; at a distance from the edge of the water of not less than 100 feet, and from the bridge ramp not less than 100, or more than 300 feet. Their floorings are well raised from the surface of the earth, in no case less than 1 foot; and in the southern divisions, where the country is flat, as well as in other parts of the canal where dampness is a characteristic of the country, the plinths of the chokies have been laid on a level with those of the pillars and parapets of the bridges to which they are attached. As a general rule, these chokies are well raised, and the accommodation is free from all the inconveniences to which similar buildings have been subjected on the Jumna canals, from the want of elevation.

In cases where first class chokies have been built in connection with falls and locks, their situation is centrical

between the main and navigable canals, and on the up-stream side of the road that connects the bridges which have been built over the works.

The general position of these buildings has been determined with reference to the supervision of the rajbuha or water-course heads in their immediate vicinity. Their position relatively to the bridge, viz., on its up-stream side, has been selected, that advantage might be taken of the prevalent direction of the winds, which during the dry season would act in carrying the dust from the bridge ramps away from the choki, instead of towards it. A consideration of no little importance to the convenience and comfort of the residents in the choki.

The first class chokies have been built all the way down the line of the canal and its branches, at distances of about 12 miles, or varying from 12 to 15 miles apart. The specific object for which they have been built, and on which their distances from each other have been determined, is to keep up an open line of communication from one end of the works to the other. To afford the means at all seasons of the year, for either inspecting or executive officers, to visit at the shortest notice any point of the works which require his presence, and to relieve both the Government, and the supervising establishment from the evils and inconveniences which, during the rainy months, might arise from difficulties in marching and moving, were no accommodation of this sort provided.

With the above object in view, it will be clear that these buildings are not intended as private residences, or for the occupation of the European members of the establishment beyond limited periods. Permanent residence, or occupation for lengthened periods, would evidently defeat the object for which the buildings have been erected. The chain of open posts, by which the maintenance of a connected line is contemplated, would

no longer exist, were even one of these buildings occupied by a family, or by an individual whether connected with the canal establishment or not. Considering that the purposes for which the Government has been advised to erect these buildings, are entirely of a specific nature, the conversion of the accommodation which they provide to objects foreign to the intention on which they were built, can hardly be too vigorously protested against. The rule that has been usually observed on the Jumna canals with reference to choki occupation, is that the parts of the building which are expressly intended for the commissioned and non-commissioned staff, should be reserved for their accommodation; but that, in the absence of the former, the non-commissioned staff may use that part of the building which is intended for the superior grade, on certain conditions, solely appertaining to protection of property and cleanliness of occupation. Juniors in either grade are supposed to give way to seniors; and unless under specific orders in writing, no individual is expected to hold residence beyond two days. In every case it is expected, moreover, that people who take advantage of the accommodation, should consider themselves answerable for the property: for the glass in the windows, and for the general preservation from injury of the house and its appendages.

The case is one, however, upon which it is impossible to lay down determinate rules. Heavy repairs during a period of the year when a European is called upon to move out to a distant choki, may detain him for an indefinite period as a resident in one of these buildings. In such a case, the building could hardly be considered as turned from its legitimate uses. Excess of work on matters connected with revenue, might detain either the director or any of the executives, for an equally indefinite time at one of these chokies. Under such circumstances

a continued occupation would be perfectly fair. The object being understood, it appears to me, to be sufficient to carry it out according to its true spirit, abiding, as far as possible, by written rules which, emanating from the *directors' office*, would be the code for general guidance.

These rules ought to be hung up, both in the centre room, and in that one in the verânda occupied by the non-commissioned staff, of every first class choki; and the chokidar or chuprassi in charge ought to be made responsible for the furniture, glass, doors, windows, and the state of the building generally; reporting the dates of arrival and departure of every person who occupies the building; and noting the way in which the property has been treated. Unless stringent rules are laid down for the prevention of injury, not only to the glass, furniture, and woodwork, but to the stucco and walls of the building (laying aside the carelessness and indifference with which Government property is treated, in some instances, by people who ought to know better), the servants attached to our establishments, whether private or public, are frequently the cause of a wanton destruction to property, when such property does not belong to their masters. It is necessary to prevent this, and it can only be prevented by active legislation.

The ground in the neighbourhood of these first-class chokies ought to be kept in order, clean, neat, and free from deformities of any description. Above all things its drainage ought to be properly attended to, full conveniences being provided in the inlet which is attached to the bridge works, and which is situated in the choki yard. In all cases, however, I would look upon this inlet as a secondary means of relief. If possible, advantage ought to be taken of the natural slopes of the country, and a spacious channel ought to be excavated, so as to carry the drainage water, not only away from the

choki yard, but away from the canal altogether. It will be understood from what I have said elsewhere in these pages, that the object of the inlet which is attached to bridges, is to relieve the country from the water collected by the interposition of the ramps of the bridge, and by their interference with the drainage of the country.

The mangoe graft plantations, which are intended to be appendages to every first class choki, may be the means of adding greatly to their convenience, as well as to their appearance. Under an officer who takes an interest in the order in which his division is conducted, and in the state in which his building and their dependencies are maintained, the first class chokies, and their appended plantations, may become most desirable places of resort. In exemplification of which I could point out stations on the Eastern Jumna Canal, established by Mr. Deputy Superintendent Brew of the Canal Department; which, without any additional outlay, and merely from that natural attention which is derived from the possession of a large development of the organ of order, are equal in neatness and tidiness to the most carefully watched private property.

The area of ground appertaining to a first class choki is equal to about four acres.

The second class chokies are, with a few exceptional cases (dependent on the absence of rajbuha heads), built at every bridge on the line of the canal and branches. Their position is similar to that of the first class chokies; and the elevation of their floorings above the level of the country has been fixed on the same rules that guided me in the larger buildings. These chokies are expressly for the accommodation of the chokidars in charge of the irrigation, as well as for the tools and stores of which there are depôts at every post; the main ones being at the first-class chokies, and the subordinate ones under

charge of the chokidars at the buildings now under review. Independently of the control of the irrigation, the works in the immediate neighbourhood are under the charge of the chokidars, and the position of the building relatively to the different works, with the means of cross-communication afforded by the bridges, give him every facility of access to both sides of the canal, and, consequently, the best means of supervision.

To the second class chokies situated above the Nanoon fork no separate ground is attached. Their site is within the canal boundary, and their limits are marked by the boundary ditch. Below the Nanoon fork, and on both the Cawnpoor and Etawah terminal lines, where the canal boundary is more limited in extent, extra ground has been taken in, so as to regulate the position of the chokies, with reference to the bridges, agreeably to the rules before described.

I have described the chokies as built of "kucha pukka," or of half-burned and refuse bricks with mud. This method of construction originated in the Jumna Canal works, and was adopted with a view to economy. It was perpetuated on the same grounds in the works of the Ganges Canal; where, in addition to any advantage that might be derived from the measure as one of economy, the demand for well-burnt bricks was so great, and in many situations the difficulties of procuring them in sufficient abundance for the works that had necessarily to be built with the very best material, was so notorious, that the executive officers were put to every devisable shift to procure material at all. In devoting the peela or half-burned bricks to the building of chokies, therefore, we adopted a plan that expedited the completion of these buildings, and at the same time disposed of a species of material that would otherwise have been useless, or at any rate have been a dead loss to the Material Department.

The estimate of 1850 for chokies built on the main line, and the two branches into which it is divided at Nanoon, with the material above described, is in itself a very large item. The total amount called for, for the construction of buildings of this sort, including both those of the first and second class, was as follows:—

	RS.	A.	P.			
1st Division . . .	11,445	4	1			
2nd „ . . .	18,341	3	3			
3rd „ . . .	14,621	11	5			
Total cost of chokies on the main canal . .				44,408	2	9
Cawnpoor Branch . .	38,328	8	11			
Etawah „ . .	43,136	14	2			
Total cost of chokies on the branches . .				81,465	7	1
Grand total on the main canal and fork lines .				125,873	9	10

At the period when the above estimate was drawn up, the evil of using the half-burnt brick in that part of the building which was in connexion with the soil, and liable, therefore, to the effects of moisture, had been prominently brought to notice, throughout the whole extent of the canal. In those districts lying to the south, where the soil was impregnated with the *reh* or alkali to which I have before alluded, and where the bricks which had been made of this soil were of a very uncertain quality, the material had so completely failed, not only by the attacks of moisture, but even by the mere weathering of climate, that as far as the foundations, or that part of the building terminating on the plinth or flooring, was concerned, it had been determined in all cases where such could be done, to use a better description of material, and to reject the refuse or peela brick entirely. This, although a good determination in itself, was not brought into practice until the greater number of the buildings had been completed, and even then in some

cases, the absence of good brick necessitated the executive officer to recur to the use of the inferior material. Latterly, however, the use of the half-burned or refuse brick has been confined as much as possible to the superstructure.

With regard to the use of mud as a cementing ingredient, the defects appear to me to be great, and necessarily increasing in proportion to the thickness of the seams; to the quantity of cement used; and consequently to the size of the brick, and to the care with which the brick-laying is executed. Lime cement indurates, and is not liable to the effects of pressure after this induration has once taken place. Mud cement, on the contrary, although it hardens in dry weather, gets soft in the wet, and during that period of the year when the rain is continuous, and when everything exposed to its influence is affected by moisture; the mud cement in imbibing this moisture, becomes liable to the action of superincumbent pressure, which must tend greatly to the disarrangement of high walls, especially when such walls have the weight of a roof upon them. The consequences of this disarrangement are exhibited in unequal settlement of the walls, in the action of doorway arches upon their impost blocks, and in a destruction to the integrity of the roof. Cheap, therefore, as buildings may be, when constructed on the kucha pukka principle, they are undoubtedly subject to the above evils; and although in nine cases out of ten, careful supervision and the use of the large class of brick reduce these evils to a minimum, they must always be impending over a building, where the material in all its parts is not rigid.

I have in the following cases substituted lime for mud cement, at a very considerable excess of cost, but with a view of testing the value of this original outlay with that arising from the constant repairs to which the

kucha pukka buildings are liable. In the third division the following first-class chokies are built with lime cement:—

Estimated Cost, Mud Cement.	Material. Foundations.	Material. Superstructure.	Position of 1st Class Choki	Material. Foundations.	Material. Superstructure.	Actual Cost, Lime Cement.
RS. A. P.						RS. A. P.
1,416 5 4	Peela Bricks.	Peela Brick.	Geesoopoor	Pukka Brick.	Pukka Brick.	1,713 4 11
1,416 5 1	"	"	Moonda Khera	Pukka Bricks	Pukka Bricks.	1,696 6 3
1,416 5 4	"	"	Kasimpoor	Block Kunkur	Pukka Bricks.	1,720 14 9

These station posts were built in the cold weather of 1851–52.

In the Etawah branch, the following buildings have been constructed on the same principle:—

Estimated Cost, Mud Cement.	Material. Foundations.	Material. Superstructure.	Position of 1st and 2nd Class Choki	Material. Foundations.	Material. Superstructure.	Actual Cost, Lime Cement.
RS. A. P.						RS. A. P.
1,958 5 3	Peela Brick.	Peela Brick.	Puteekra	Kunkur	2d Class Bricks	2,544 14 0
361 13 6	"	"	Koosiarri	"	"	472 2 11
361 13 6	"	"	Lohya	"	"	521 4 8
361 13 6	"	"	Jowapoor	"	"	488 10 2
3,043 13 9	Total.				Total.	4,026 15 9

It will be observed that in the Etawah terminal line, kunkur has been used in some cases in the foundations only, in others in the whole building. The appearance of the chokies built with kunkur is exceedingly good. The colour is cold, but it harmonizes with the hot weather feelings arising from an Indian climate. Where this material has been used in the superstructure, stucco has been laid aside.

A comparison between the estimated and actual cost of the buildings above specified, as shown by the tables,

will give a clue to the amount of original outlay that the use of lime would have entailed on the Government. Whether such an outlay would have been warranted, is a question that must be tested hereafter, by the results of the annual repairs of the buildings constructed on the different systems, *the excess of cost in the one being* taken into consideration.

It would appear from the above tables, that to have constructed the whole of the chokies with lime cement instead of mud, the excess of cost would have been as follows:—

In Mr. Volk's division:—

				Mean.				Excess.
	RS. A. P.		RS. A. P.	RS. A. P.		RS. A. P.		RS. A. P.
As	1,416 5 4	:	14,621 11 5 ::	1,710 3 3	:	17,654 1 4	=	3,031 5 11

In Captain Whiting's division:—

	RS. A. P.		RS. A. P.	RS. A. P.		RS. A. P.		RS. A. P.
As	3,043 13 9	:	43,136 14 2 ::	4,026 15 9	:	57,069 7 2	=	13,932 9 0

The cost of kucha pukka as used in the choki buildings varies considerably, the maximum and minimum rates of each division being as follows:—

			RS.	A.	P.			
1st	Division,	maximum	12	0	0	per 100	cubic feet.	
	"	minimum	7	8	0	"	"	
2nd	"	maximum	8	1	9	"	"	
	"	minimum	5	13	3	"	"	
3rd	"	maximum	9	0	1	"	"	
	"	minimum	4	4	8½	"	"	
4th	"	maximum	10	4	10	"	"	Partly Pukka Brick.
	"	*minimum*	*5*	*0*	7	"	"	
5th	"	maximum	9	10	9	"	"	Partly Pukka Brick.
	"	*minimum*	*6*	*3*	*3*	"	"	

Wherever well-burned bricks have been used, a note to that effect has been made opposite the rate. This is a circumstance, to which, in drawing comparisons, most especial attention is required, the cost of well-burned brick varying from 6 to 16 rupees per thousand,

whereas the cost of the peela, or refuse ones, is only 2 rupees 8 annas per thousand.

In conclusion, I may observe that in the course of progress, improvements, and in some cases additions, have been made to the first-class buildings. In all the divisions, excepting the second, the veranda roofs have been raised an additional foot, with the object of improving the accommodation, and making the rooms cooler. In some cases, and I much regret that it has not been done in all, a staircase has been made from the floor to the roof, so as to give easy access for repairs, and during hot weather the means of approach to the upper terraces, the elevation of which affords a very agreeable and airy promenade during the close and sultry evenings of the hot weather.

In the second division, or that extending from the 24th to the 110th mile, the chokies have been constructed precisely on the same design as regards elevation as that originally estimated for. As a set-off, however, against the economy of not raising the veranda roofs, as has been done elsewhere, the executive engineer has built to each first-class choki a range of flat-roofed out-houses, containing five rooms of 10′ × 8′ each. The object of these buildings is to prevent either the European or native establishment from disfiguring the neighbourhood of the choki with huts and temporary buildings, the erection of which is in all cases prohibited. During the progress of the works—and it is during this period that the whole of my directorship has been passed—it has been found necessary to allow the construction of temporary huts for the accommodation not only of the labourers, but of the supervising establishment. Our first-class chokies have, in many cases, been built at points far ahead of the excavation and works in progress, so as to act as nuclei and head-

quarter stations to the establishment, both European and native, in charge of the advanced work. These arrangements, necessary as they were at the time, are no longer required, and the huts in question ought to be summarily removed. It appears to me to be so desirable that the ground in the neighbourhood of these chokies should be maintained in a neat and orderly state, that if the plan adopted in the second division of having a range of out-offices attached to each building be one leading to such a consummation, I would strongly advocate its extension throughout the whole of the works.

CHAPTER V.

WORKS OF NAVIGATION.

THIS *chapter is divided into three sections* :—

I. Navigable channels.
II. Navigable heads.
III. Navigable locks.

I shall, however, review them under one head, as they are too intimately connected with each other to admit of convenient separation.

In considering the term Navigable canal, in its accepted signification, viz., a channel with no current to impede or delay the passage of craft, and with the levels completed in a series of still, or nearly still reservoirs; the canals in these provinces hold no claim to any consideration, nor would works constructed on such designs either be consistent with the objects in view, nor be beneficial to the cultivators for irrigation.

There is a medium, however, in which both objects may be gained. We may dispose of the current on a regimen capable of counteracting the evils to be expected from weeds, which, either in a tropical, or semi-tropical climate, would inevitably attend upon still water; and we may, by lockage arrangements attached to the masonry descents, provide ample means for the passage of boats.

The Ganges Canal works, which are specifically for irrigation, come in a great measure under the above category. The channel is, on its open course, applicable

in every way to the passage of boats; the interruptions to this open channel, which are caused by the masonry descents, are counteracted by lines of safe and commodious transit, which, being carried in a circuitous direction, and at considerable distance from the main canal, are *placed out of the influence of the rapids*. On these circuitous lines the difference of level is gained by lockage, and every convenience is afforded to the passage of craft, both in facilitating its progress, and in providing for its security.*

As a navigable line, under the restrictions which the more important objects of irrigation impose upon it, the Ganges Canal will afford the means of water-carriage from the point where the main river leaves the mountains, through the heart of the Northern Doab. It will, by regaining its parent stream at Cawnpoor, offer a compact and safe line of transit, to the avoidance of the shoals and rapids which are the characteristic feature of the main river. By its junction with the Jumna, near Humeerpoor and Kalpi, a new link will be provided to the water-carriage of the country; and as I have remarked elsewhere, its relative position to all the rivers that run parallel to it, provides the means of still further extending its usefulness, by the *adaptation of locked*

* When the falls for regulating the levels of the bed were constructed on the Eastern Jumna Canal, the chamber on the left side was fitted with gates for the purpose of lockage. The plan was inexpensive, attended by no interference with the object for which the falls were built; and it demanded the mere application of upper and lower gates, which, if required elsewhere, might easily be removed. With the exception, however, of the locks in the southern division, where the body of water was comparatively small, and where the working of them was under the eye of one of our best overseers, none of these locks have been used. The danger arising from the proximity of the lock channel to the open overfalls, and the fear of being engulfed in the latter, may possibly be the cause of the non-acceptance of the Eastern Jumna Canal as a line of water carriage. The remedy, if this is the case, is by a side channel, as adopted on the Ganges Canal works above described.

channels, and by their means connecting the inland towns or commercial marts with the navigable rivers.

I have drawn attention to a navigable branch that might be constructed from the main canal near Moradnuggur to the Hindun River; as well as to one that might be taken from the Bolundshuhur branch, *viâ* Belaspoor, to the Jumna River. Both these lines would reach the Jumna at points nearly identical, the former having the disadvantage of having had to navigate the tortuous course of the Hindun River; the latter having been altogether confined to artificial, and, therefore, compact lines. Both of them open out new lines of country to which the means of water-carriage would be acceptable; and both of them, therefore, are perhaps worthy of consideration. By looking at the map, however, it will be evident that there is no limit to the means provided for the adaptation of the canal to water roads, and to their being linked on to the side rivers. The rajbuhas, even in themselves, will, I doubt not, become the medium of providing the inland villages with hill produce, especially with the smaller class of rafter for house building, which is now unattainable from the cost of land carriage.

Before entering upon the detail of construction and design of the different works to which this chapter is devoted, it will be necessary to explain the especial objects by which I was guided in their elaboration. The changes that have taken place in the disposition of the works in the Khadir, sufficiently account for the redisposal of the channels for navigation. To the works, therefore, that have actually been built, I shall confine myself; and these (with the exceptions above noted) are similar in general respects to those of the 1845 estimate.

In the design for the navigable channels, I was guided by the following considerations:—

1st. The necessity of an alignment at a sufficient distance from the works on the main canal, to prevent either one or the other from being incommoded by too close a proximity.

2nd. To place the point of departure of the navigable from the main line at such a distance from the falls that it might be entirely free from their influence.

3rd. To protect the head of the navigable channel, and to make the best arrangements for securing the safe admission of craft.

4th. To adapt corn mills to the waste channel of the locks, and to make it generally applicable to the purposes of machinery.

5th. To combine with the masonry works attached to the locks, such inlets for drainage, and such outlets for irrigation as might be required from that particular part of the canal in which the works were constructed.

The dimensions of the channel, as well as those of the lock chambers, were determined on the length of the largest sort of kurri or rafter into which the saul timbers of the forest are cut up for the country markets. This species of wood, which varies from 10 to 15 feet in length, and from 3 to 6 inches in scantling, is sold in enormous quantities, and is in general use throughout the North-Western Provinces, wherever it can be obtained at a reasonable price. It is collected at marts situated on the banks of the great rivers in the neighbourhood of the forests, and from thence it is floated down on rafts to depôts, from whence it is distributed over the country. The kurries of 15 feet are tied side by side, and form longitudinal rafts, frequently of immense length, but in width confined to the length of the kurri. By making the navigable canal channel, therefore, equal in dimensions to the section which I have shown in diagram 121, and by designing the lock chambers on a width of 16

feet, I gave every facility to the passage of the same species of raft that now traverses the main rivers. I avoided the necessity for alteration in the form of rafts, and I did not demand any change in the method to which the boat people and rafters have been accustomed. By giving a length of 100 feet in the clear to the lock chamber, the size of raft which will be able to pass down the canal will be equal to the average of those which are now floated down the Ganges. The width is a convenient one, and admits of the utmost simplicity in the gate and sluice apparatus.

The question of the greatest importance after the dimensions of the channels and lock chambers were decided on, appeared to be that which comes under the third item. It was very clear that to consider the main line as a navigable one, with the prospect of boats or rafts being brought in contact with the falls, was unreasonable. It mattered little whether through carelessness or accident boats were overwhelmed in these cataracts. Catastrophes of this sort were to be avoided. The notorious apathy of native boatmen was well known; the carelessness and neglect of establishments were contingencies of too frequent occurrence to be treated with indifference; and the possibility of craft passing the navigable head, and proceeding onwards towards the falls, was obviously a matter to be guarded against. It was a case in which no half measures would answer, and one in which the prevention to danger ought to be so certain that no reasonable contingency should be likely to defeat it.

The original idea was to throw chain booms over the main canal immediately, on the down-stream side and below the head of the navigable channel. The objections to this plan, however, were the uncertainty of obstruction that booms would offer, especially under the extreme

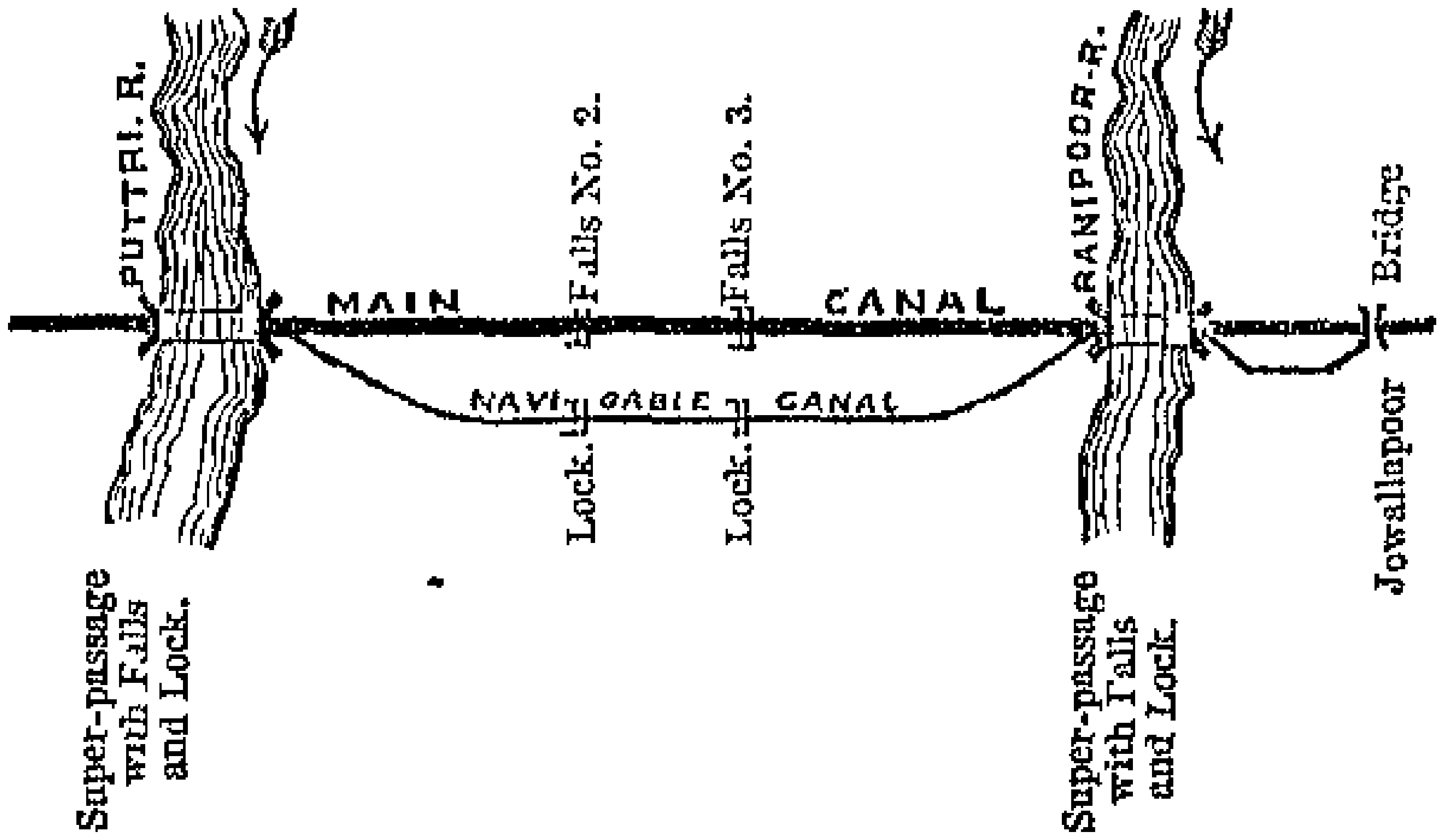
variations of high-water level, to which the canal was subjected. There was much in the practical detail, moreover, of the design, that rendered its adoption inconvenient, and the mere facts of doubts existing as to its sufficiency appeared to me to be fatal to a project upon which the security of property, and even of human life, depended. In lieu, therefore, of chain cables suspended across the main channel, a bridge of boats has been substituted. The passage of traffic, therefore, is entirely confined to the open channel above the bridge, which acts as a finger-post in directing the boatmen to the navigable canal head, and opposes a direct bar to the advance of craft beyond the limits of safety. The bridge itself, although not designed as a high road for communication, affords the means of crossing the main channel, and of placing the canal establishment in connection with a rajbuha head which is situated on the right embankment, and on the up-stream side of the bridge. The bridge, moreover, will, to a certain degree, act as a bund, and by retaining the water on the up-stream side, on somewhat higher levels, give to both the rajbuha head on the right bank, and to the navigable channel on the left, the advantages attendant thereupon.

The works under this design offer a security to boats in their passage, which otherwise they would not have had. The chances of accident are indefinitely removed, and the advantages arising both to irrigation and navigation appear to me to be conclusive as to their fitness for the purposes required.

I now proceed to the detail of the navigable lines, and the different works therewith connected. In their order of precedence those in the Ganges khadir will be first described, and to do this satisfactorily, I must introduce a repetition of diagram 14, fig. 2, which was formerly given as illustrative of the change that had been made in

the disposition of the works between the Ranipoor and Rutmoo torrents.

Diagram 119.



The object of the navigable channel in the khadir is to overcome a descent of 36 feet, that occurs between the Ranipoor and Puttri super-passages. The distance between the two works, or between the two extremes of the high and low level, is only 4·6 miles; it was considered, therefore, expedient to design the whole in one uninterrupted channel for navigation, instead of in a detailed series appended to each particular descent. The navigable channel, accordingly, which leaves the main canal on its left bank, immediately on the up-stream side of the Jowallapoor bridge, runs parallel to it, impinges on the super-passage at Ranipoor, under which its channel is carried, and from thence gaining its parallelism, meets the main canal below the Puttri super-passage, under which its course is conducted on the same design as that at Ranipoor.

The Jowallapoor bridge acts towards the head of this line of navigation in the same way that the bridges of boats before described are intended to act at points where there are no masonry bridges. It offers a marked and decided limit to the water available for navigation, it is far removed from the head of the falls; and by occupying each bay, which is 55 feet in width, by three boats

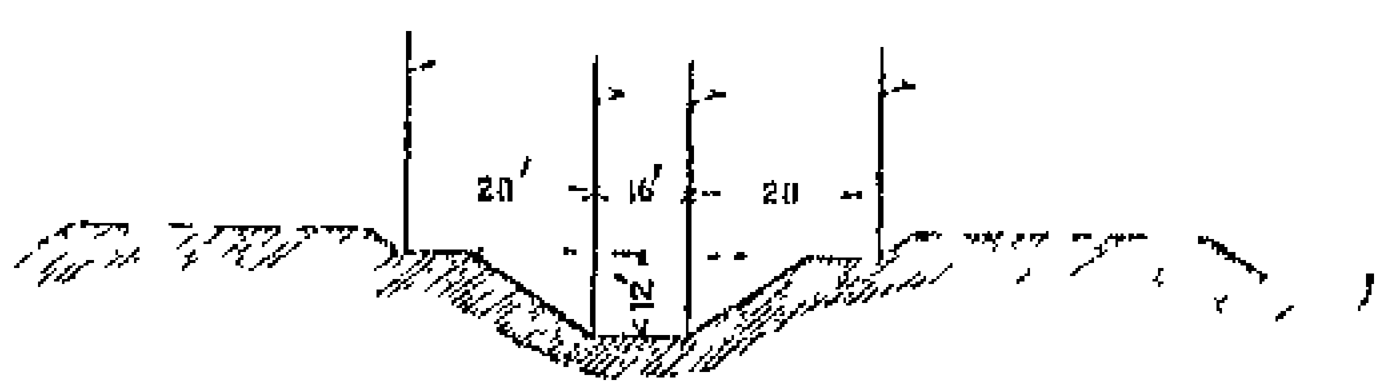
anchored and firmly held in position, so as to prevent the passage of craft beyond its limits, our object is secured with the smallest possible interference, and with as little obstruction as could well be, with the passage of the water in the main canal.

The head of the navigable cut consists of an arched masonry channel 20 feet in width, giving cover to a towing-path of 5 feet, and a water channel of 15 feet in width. This channel passes obliquely through the bridge, wings and ramps, leaving the main canal at an angle of 40°. Drop gates are fitted to the front, so as to admit of the channel being laid dry for repairs, or for other contingent purposes; and the entrance into the arched channel is flanked by masonry walls, with piling, and the necessary expedients for protecting the work from injury. The whole forms a component part of the Jowallapoor bridge, to which it becomes a leading feature on the up-stream left flank, the remaining three flanks being covered by the Dalhousie Ghats.

The work, with the exception of the foundations and the more solid parts of the abutments in which boulder masonry is used, is constructed entirely of brick. The arch, which is a segment of 60°, is sufficiently elevated to admit of free passage for loaded boats with a maximum supply of water in the canal. (*Vide* Atlas, Plate XVIII., fig. 4.)

After leaving the masonry head above described, the channel, which is excavated in a soil somewhat sandy, and on the following section,

Diagram 120.



proceeds for a distance of 1,839·66 feet on a curve, with

a radius of 2,256 feet; it is then carried for 4,868 feet parallel to, and at a distance of 600 feet from, the canal boundary, until it reaches the neighbourhood of the Ranipoor super-passage, immediately in front of which the first series of locks is established. At a distance of 615 feet from the up-stream face of the super-passage works, a revetted and floored masonry channel, 16 feet in width at its commencement, directed upon the works in a curve, delivers the water on the head of the lock chamber, at which point the width of the channel is increased to 30 feet. This masonry channel, which commences immediately below an octagon harbour, or resting-place, into which the navigable channel is directed, is entered under a masonry bridge, with a segmental arch (60 deg.) of 25 feet in width, 9 feet of which is occupied by a towing-path. The channel then sweeps round a first-class choki, which is situated in an elevated position on the right; and between which and the channel access is gained by a flight of steps, and proceeds onwards. On the approach to the head of the lock, this masonry channel throws off a branch running parallel to it, and passing under the floorings of the super-passage, in the same way, although on a higher level than that of the navigable line. Both these channels form flanked archways, designed uniformly with those for the passage of the water in the main canal, from which they are separated by a masonry revetment. The archway for the navigable line is 19 feet in width, and that for the parallel passage, which is intended for the supply of corn mills at Bahadoorabad, is 10 feet. Both the supply heads of the corn mills and the passage for boats are thus brought to bear upon the Ranipoor super-passage, of which they form component parts; the floods of the torrent passing over the whole, without in any way interfering with their respective channels.

The height of the revetment, or wall, that separates the navigable passage and the lock chamber from the main canal channel is 15½ feet, the width giving space on the side towards the main stream for a parapet of 3 feet in height. The difference in width between the lock chamber, which is 16 feet, and that of the archway under the super-passage, in prolongation of the lock chamber, which is 19 feet in width, has enabled me to terminate the revetment of separation above described by a flight of steps, connecting the higher with the lower levels, and giving access to the navigable channel under the archway.

For the purpose of regulating the supply in the channel, three sluice openings of 6 feet in width each, have been pierced through the separating revetment, at a point immediately above the head of the lock chamber.

For the general design of the locks themselves, with the detail of the apparatus for fixing the gates, filling and emptying the chamber, &c., I am indebted to my visit to, and to my inspection of, the works of this description in Lombardy. There can, I think, be no difference of opinion on the extreme simplicity of these designs, which will be better understood by reference to the Atlas, Plate XXIII. The upper gates, which are comparatively small, being in height 6½ feet, are held in position by a plain wooden cross, in the place of the complicated collars; and the lower ones, for the retention of which in their proper position greater care is required, are immovably fixed by a timber laid transversely across the chamber, capping the upper pivots of the gates, and having its ends imbedded in the masonry work. By imbedded, it is not meant that the timber is irremovably built into the masonry, it is merely laid in grooves adapted to its reception, and out of these grooves it can be removed, and the gates displaced, without the

slightest disarrangement to the building. In both the upper and lower gates the lower pivots are seated in the usual way, in stone blocks; in the present case, the blocks are of the Delhi quartz rock; they are, in fact, corbels from the ruins of old Delhi.

The same corbels have (fixed in an upright position), been used as bumping stones for the gates to shut upon; this plan has been adopted universally in the room of the unbroken line of stonework in use, both in England and Lombardy, which it was supposed would lead to interruption in the working of the gates, by collecting sand deposits.

The sluices for filling and emptying the chambers, the simplicity of which attracted my attention when on the Pavia Canal more than anything else that I observed on the Italian canal works, are really exaggerated stop-cocks; that is to say, solid cylinders pierced through on one side, so that when the side that is pierced is opposed to the channel, water escapes; by turning the cylinder and opposing to the water the unpierced side, the sluice is closed. From the shape of this machine which is cylindrical, and measuring 2½ feet in diameter, by 3½ feet in height, we have, for want of a better, called it a "drum sluice;" it is worked by an upright axle, which is carried up through the revetment and is terminated by a handle or lever, fixed at right angles to it. As in the case of the lock gates, its lower pivot works upon a stone block. (*Vide* Atlas, Plates XXIII., fig. 4.) These sluices are fixed on a low level, so that when the admission of water into the chamber is required, every advantage is derived from head pressure, and by this, to rapidity in filling the chamber.

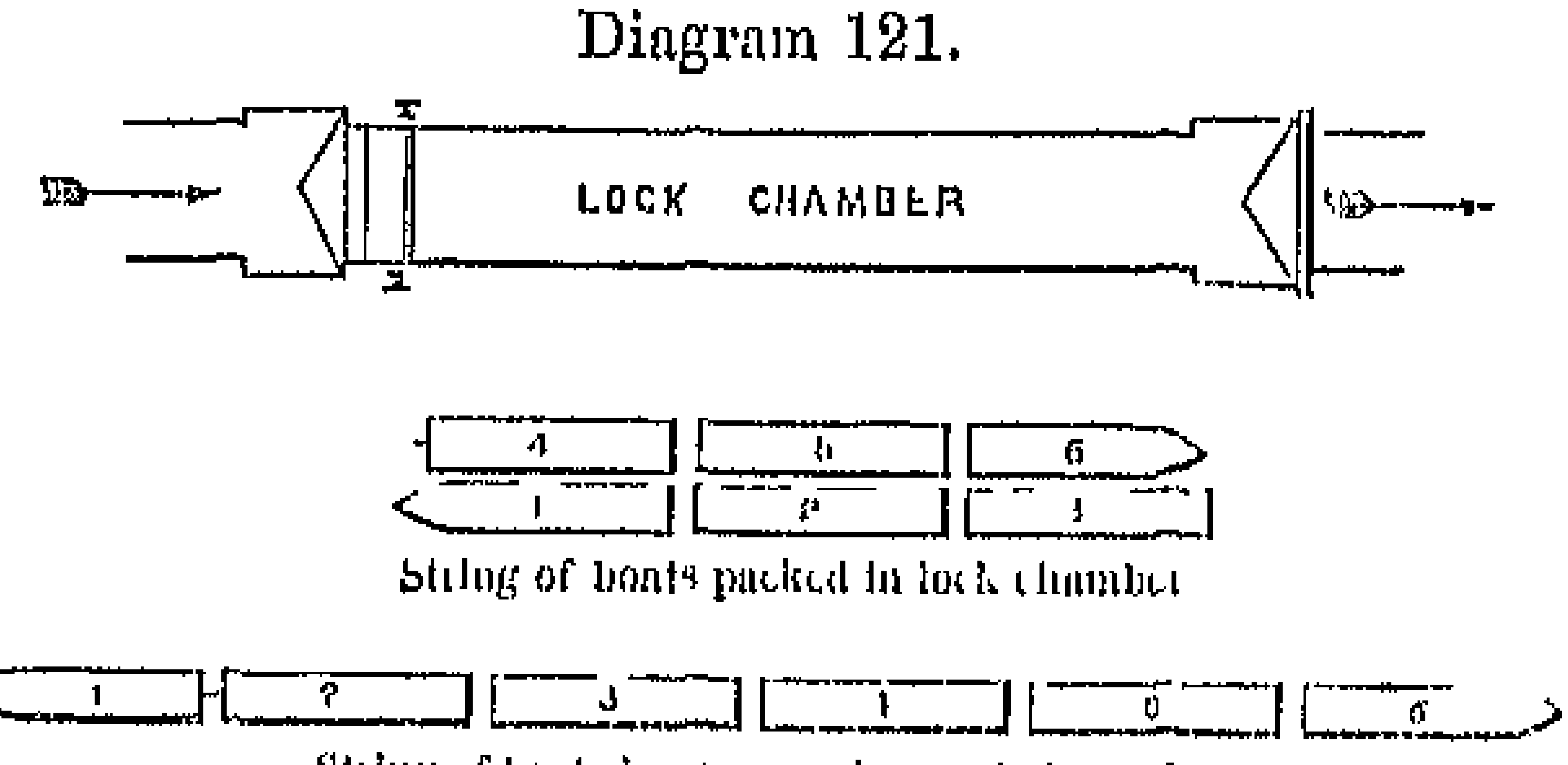
The ease with which these sluices are worked, their utter independence from all rackwork, chains—in fact from all vertical motion—renders them of extraordinary

value on works which are entrusted to the charge of simple and uneducated establishments. I may remark also, that the adaptation of complicated machinery, or simple machinery even, which is liable to disarrangement, might be fatal to the use of works of this sort, in the absence of means for its immediate repair.

A question, however, still remains, dependent in a great measure on the horizontal movement, which appears to be so admirably adapted to security: May not the sand and silt deposits, which are to be expected in the Ganges Canal works affect the working of these sluices? Even this evil, should it occur, may perhaps be remedied by a standing order for turning them twice or thrice a day, should the locks be out of employ.

The dimensions of the lock chambers are 16 feet in width on a total length of 100 feet, the drop being 9 feet in perpendicular height, with a reservoir at its foot; the width is adapted to the larger sort of kurri, or rafter of 15 feet in length, and to the raft which is used on the Ganges, as before explained. It is also adapted to a string of boats, as proposed to be used for the transport of material, &c., on the works, the design of which is shown in the following diagram:—

Diagram 121.



I have adopted the timber apron as shown in the diagram at x x, for the purpose of keeping the boats clear of the drop, and for breaking the fall when water is

permitted to pass over in large bodies. This apron is used in all the lock chambers that I visited in Northern Italy, and its advantages were so highly spoken of by the engineers who accompanied me, that I have no doubt time and practice will prove its applicability on the works in these provinces.

The whole of these buildings are, with the exception of the more massive parts of the abutments and foundations, which are of boulders, built entirely of brick masonry. The lining out of the curves of approach to the super-passage has been admirably executed by Mr. Kay, the assistant engineer in charge of the works, and the bricklaying and work in general have been well done.

On leaving the super-passage, a masonry channel carried on an ogee curve, similar to that on which the navigable line reached the work, delivers the water on an excavated canal which runs on the left, first on a curve 1,010 feet in length, and then parallel to, and at a distance of 531 feet from, the main canal boundary. The length of this curve and of the masonry channel from the down-stream face of the super-passage to its termination on the earthwork, is equal to 415 feet. The above masonry channel, the revetments of which are 12·65 feet in height, is crossed by an aqueduct for conducting the mill supply, which up to this point runs parallel, although, as it will be understood from the purposes for which it is intended, on a much higher level.

Shortly after the masonry works in connection with the super-passage are passed, the excavated channel is widened out into an octagon reservoir for the purpose of acting as a harbour and resting-place for boats on their reaching the lock passage. At a distance of 4,140 feet in advance, we reach the Bahadoorabad mills, which lie on both sides of the navigable channel; and in advance of these again, at a distance of 3,834½ feet,

are No. 2 Locks, the bridge over which has its axis in prolongation of that of the falls bridge over the main canal; a method of alignement which has been designed for all the works connected with navigation.

The works at No. 2 Locks consist of a lock chamber, with its dimensions and fittings on the same plan as those before described. On the right of the lock channel is a waste one, 11 feet in width, to which the necessary appliances for regulating the escape water have been attached. Both channels are crossed by masonry segmental arches, forming a bridge with a roadway 25 feet in width, between the plinths of the parapets. The lock and the waste chamber are separated by a wall which gives a platform on its top of 9 feet in width. On the down-stream side, this platform is terminated by a flight of steps, affording the means of approach to the water from the bridge roadway. The side or abutment revetments are terminated both on the up- and down- stream extremities by sweeps, which are well covered by the slopes of the excavated channel.

An open line of canal in prolongation of that before described, delivers the water on No. 3 Locks, the position of which, relatively to No. 3 Falls on the main canal, is uniform with that before described. With the exception of the bridge roadway, which is 15 feet, the works at No. 3 Locks are similar in every respect to those at No. 2; their dimensions and design are identical.

At a distance of 600 feet, the excavated channel retains its parallelism to the main line of canal, arriving at the Puttri super-passage precisely under the same conditions as regards alignement and works as it did on its approach to the Ranipoor torrent.

The curved masonry channel, which is 599½ feet in length from its commencement to the up-stream face of

the Puttri super-passage, is entered under a masonry bridge similar to that at Ranipoor. The channel sweeps round a first-class choki, which is situated in an elevated position on its right, the higher platform being connected with the water by a flight of steps. The lock, both in its position and appurtenances, is precisely the same as that at the Ranipoor works; the lock chamber, however, delivers the water into a channel of 25 feet in width, instead of into one of 19, and consequently the revetment separating the navigable from the main canal is 13½ instead of 7·4 feet in width, and the flight of steps is 9 feet wide instead of 3 feet. The difference in the design of the two works in the above respect is purely accidental. At the Ranipoor works we were restricted within limits bounded by the inlet and outlet that had been previously built. At the Puttri works we were unshackled. We had, moreover, at the Ranipoor works to arrange for a passage for the mill-water for the Bahadoorabad mills, a necessity that did not exist at the Puttri works, where, with the exception of the archway required for the purpose of the navigable canal, the work was devoted entirely to the passage of the main stream.

On passing the lock, the boats are delivered on the lower levels into the main canal. They have, in the four locks already passed, overcome a descent of 36 feet. From the left channel, therefore, of the Puttri works, the navigable canal joins the main stream down which the boats proceed without any further interruption until they reach the high land of the Doab.

The channel and lock works at the Puttri are entirely built of brick masonry, with the exception of portions of the most massive parts of the structure, in which boulders have been used. This, in fact, is the character of all the masonry works attached to this line of naviga-

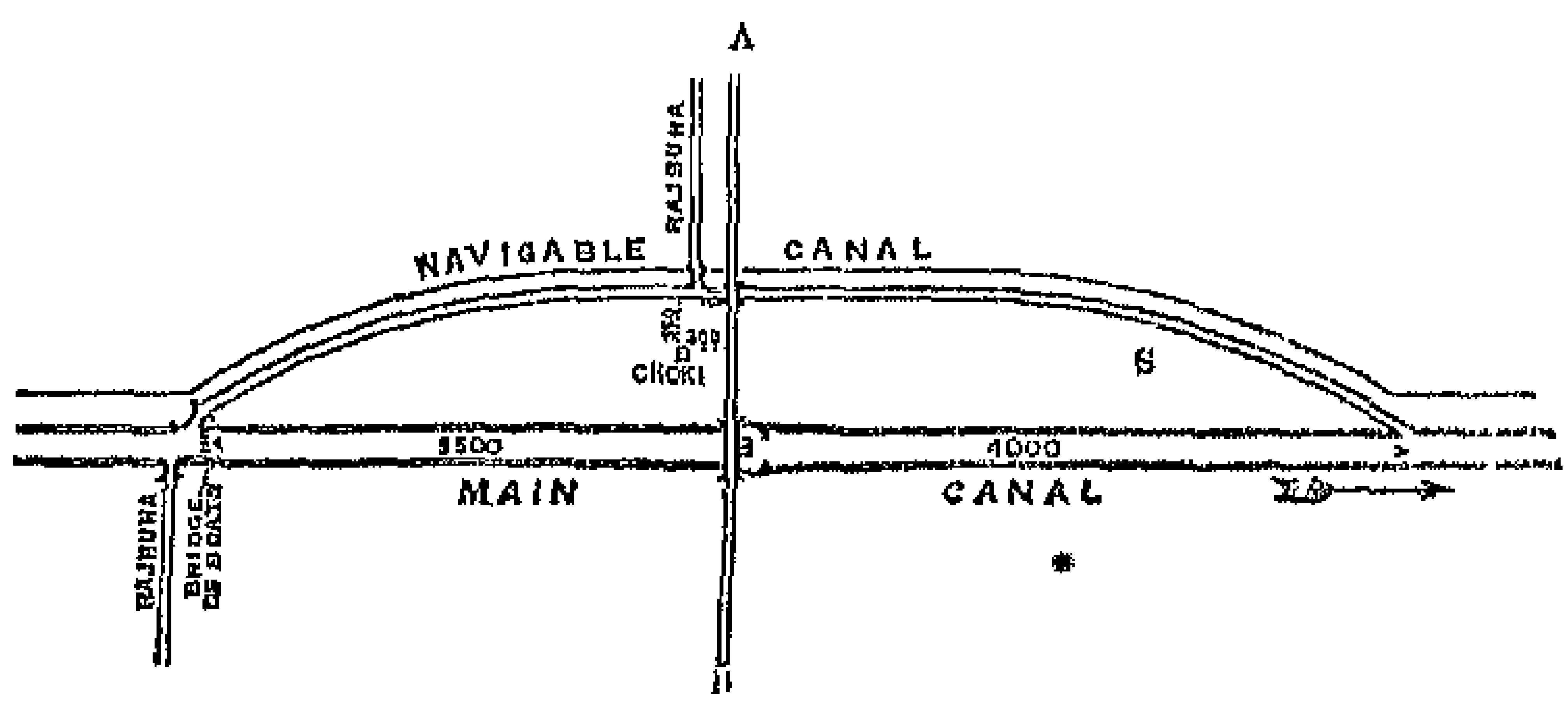
tion. Externally they are stuccoed, or covered with a coating of lime cement.

From the head at Jowallapoor down to within half a mile of the commencement of the masonry channel at the Puttri, the excavation of the channel and foundations for the works were not incommoded by spring-water, and were therefore executed without the slightest inconvenience. The whole of the works connected with the Puttri, however, have been laid in springs, and have been built under difficulties of no ordinary nature.

The former were constructed under the management of Mr. Kay, and the latter under that of Mr. Login, the assistant engineers, to whose care the whole of the works on this part of the khadir have been entrusted.

From the above description, it will be understood that the lockage in the khadir is confined to the tract lying between Jowallapoor and the Puttri, and that on this distance the channel for navigation continues uninterruptedly, and on a course entirely distinct from the main line of the canal.

Diagram 122.



We now come to the passage of the falls which lie below Roorkee, or those on the high land, the description of which is given in the second section of the first part of this history. Here, in contradistinction to that above described, the navigable passages are carried round each

descent separately, and they are necessarily accompanied by works of a somewhat different description. Diagram 122 will show in detail the relative positions of the navigable and main lines of canal and the different works attendant thereupon, under the design which I am now about to describe.

On the above plan the passage of all the falls lying below those at the Puttri super-passage is effected. These works are ten in number, and they extend from the Assoffnuggur Falls, which are situated at the 24th mile, to those at Simra, the last of the series, and which are built at the 164th mile from the regulating head at Myapoor.

The relative situations of these works will be shown by the following table, which exhibits in a parallel column the amount of drop which the change of level necessitates at each of the locks which are appended to the different works:—

	Position on the Canal.	*Amount* of Drop.
Assoffnuggur Falls	24th mile.	8 feet.
Muhmoodpoor Falls	31st "	8 "
Belra Falls	42nd "	8 "
Jaoli Falls	48th "	8 "
Chitowra Falls	55th "	8 "
Sulawur Falls	68th "	8 "
Bhola Falls	84th "	8 "
Dasna Falls	106th "	8 "
Pulra Falls	149th "	5 "
Simra Falls	164th "	5 "

The reasons why the navigable canal was not carried in one consecutive line, and parallel to the main stream, as has been done in the khadir, were—the length of the extreme distance between the head and the tail of the descents; the great quantity of valuable ground that would have been occupied; and the expense that would have been incurred, not merely in additional bridges for cross-communication, and in the excavation originally

required, but in the after maintenance of such an extended channel. On the other hand, there were very great recommendations in favour of the continuous line: the head works of the cuts, which, with their boat bridges and apparatus attached, are expensive items in the cost of these works, would have been reduced from ten to two; the inconveniences which are anticipated from the silting up of the mouths of the navigable cut heads would have been reduced in a similar proportion; and there can be no doubt that an entirely detached passage would have been more secure for the transit of boats and rafts than the main channel; but it must be taken into consideration, that the excavated line of the navigable cut would under this arrangement have either required to be of greater capacity, or it must have been fitted with numerous harbours or resting places, which, like sidings on railroads, would have been necessary for the free and uninterrupted passage of boats and rafts moving up and down stream. In balancing the advantages and disadvantages of both methods, I determined on that which has been adopted, and although it would be a source of regret to find my anticipations of its benefits unrealized, I should have the satisfaction of knowing that the method I have rejected is still available, simply by extending and prolonging the earthen channels.

In the works, therefore, connected with the detached falls which I am now about to describe, the line A B formed the axis on the centre of the bridges of communication across the falls and locks. From this axis the entrance and exit of the navigable channel are fixed at 3,500 and 4,000 feet respectively from the head and tail of the falls; a distance that was supposed to be adequate to removing these points out of the influence of the rapids. The main and navigable canal are 1,000 feet apart from centre to centre, and they are connected at

the entrance and exit by curves, as shown in the sheet of the Atlas in which the detail of projection is given. The alignements, therefore, form an island, of which the length is 7,500; and the breadth 1,000 feet. This enclosed tract is used for plantations, and as the site of the choki (in most instances a first-class one), which is centrically situated between the navigable and main canal, and on the up-stream side of the road that connects them.

The head of the navigable canal consists of an open revetted passage 16 feet in width, the left revetment meeting the earthwork by sweeps, and in some cases by flights of steps. The right, or that which constitutes one side of the enclosed angle between the two streams, is connected with a similar revetment, which forms the other, resting on the left of the main canal. These two revetments, the one forming the right of the entrance into the navigable cut, and the other that of the left flank of the main canal, meet each other at their ends in circular sweeps. The whole building forms an oval, narrower at one end than at the other; that end which is narrowest being salient towards the stream.

The revetment which faces the main canal is fitted with iron rings, placed in three tiers, which correspond with similar appendages attached to a revetment built on the right of the main canal.

Between the two revetments a bridge of boats will be thrown, held in position by chains fixed to the rings, and by screw piles, adapted to moorings in the canal bed.

The object of the three tiers of rings is to accommodate the bridge to the fluctuations in the rise and fall of the water; and the revetments to which the rings are attached are designed with flights of steps on the upper 6 feet of their height, so as to give the means of approach to the bridge roadway under these fluctuations.

Attached to the up-stream side of the revetment on the right of the main canal, is a rajbuha head. The connection between the two works has been formed in a variety of ways adapted to the particular position of the work. In some cases by flights of steps or ghats, in others by a mere continuation of the wall.

The passage into the navigable canal is an open one, without arch; it is fitted with grooves and the necessary apparatus for shutting out the water, or regulating the supply; the planks or sleepers necessary for this purpose being used in the interim as a temporary means of communication across the passage. A swivel, or moveable platform, might with great advantage be adapted to this passage.

I may observe, in closing the description of these head works, that a flight of steps is constructed in the salient end of the building which separates the two streams, by which means access is given to the upper platform of the work, and to the island at the point of separation of the channels.

The detail of the boats and apparatus for fixing the bridge in position, is left for future determination and adjustment; practice and experience will, I have no doubt, render this part of the design a simple one. In the meantime I have adopted the iron open boat in present use on the canals in these provinces, the dimensions of which are: length $30\frac{1}{2}'$, breadth $9\frac{2}{3}'$, depth $2\frac{1}{4}'$. Seven of these, with intermediate platforms, will be required at each of the heads from the Assoffnuggur to the Dasna works. The bridges at Pulra and Simra, where the main canal is reduced in width, will not require more than six boats each. I have preferred boats to pontoon cylinders, because the former are available for all sorts of useful purposes, whereas the latter are limited to one. By using the same sort of boat, however, in the bridges

that is proposed to be used on the canal generally (*vide* diagram 121) for the transit of goods, there would be less fear of interruption in the event of repair. These bridges, moreover, might be considered as the hospital for craft which had seen better days, and whose time might be more valuably spent in retirement than in the active duties of its profession.

The locks and waste channels are identical in every way, excepting in height, with those that I have before described as built at No. 2 and No. 3 of the khadir series. The depth of the revetments varies with the theoretical maximum high-water mark in the canal; for instance, from Assoffnuggur to Jaoli, where the maximum high water is 10 feet from the canal bed, the revetments on the upper sill of the lock are 11 feet. From Chitowra to Dasna inclusive, the theoretical depth of the water being 9 feet, the height of the revetments is 10 feet. At Simra and Pulra, where the depth of canal water is 8 feet, the height of these revetments is 9 feet only. By adding to the above-mentioned heights the amount of drop on each lock, the depth of gate in the lower chamber may be estimated. The following table will show this in detail:—

——	*Upper Chamber.*		*Lower Chamber.*	
	Height of Revetment.	Height of Gate	Height of Revetment.	Height of Gate.
	Feet.	Feet.	Feet.	Feet.
1. From Assoffnuggur to Jaoli inclusive .	11	10	20	19
2. From Jaoli to Dasna inclusive . . .	10	9	19	18
3. From Pulra to Simra inclusive . . .	9	8	18	17

With the above exception, the works, as far as lockage is concerned, are identical.

At the No. 2 and No. 3 Locks in the khadir, I have terminated the flank revetments on the up-stream side by sweeps into the bank. In those which I am now describing, these revetments are prolonged up-stream; that one on the right forming the front to a series of inlets to corn-mills; that on the left terminating in a rajbuha head. The design will be best understood by reference to Plate XXIX. of the Atlas. I have, however, for the present restricted the number of mills (the punchukki of these provinces) to four, for which two houses are built. The revetment is of a length, however, sufficient to admit of a third house adapted to the same number of punchukkies. For this all necessary arrangements have been made, by lining out the dimensions on a uniform scale with the basement fronts of the houses, and by building inlets for the mill shoots, which for the time being are filled with brickwork. The inlets of these mills leave the channel on the high levels, the water being retained for the purpose by the regulating shutter at the head of the waste channel. The tail or escape water passes away on the lower levels.

This waste channel is converted into a receptacle for the surplus water that falls on the island; and in the neighbourhood of the mills the water is received into a well, and passes into the chamber by an underground channel on the same plan as has been universally adopted in the Ganges Canal works.

In occasional instances where the inlet drain above mentioned is insufficient to relieve the island from rainwater, another work on the same plan has been constructed on the down-stream side of the locks, as shown in the diagram at S. In this case the front towards the water is covered by a flight of steps.

The excavated channel is on the same plan and of the same capacity as that described in the khadir, of

which a section is figured in diagram 120. The left bank forms the road and plantations, as are described elsewhere. The details of earthwork, with two exceptions, which I shall describe presently, are, as a general rule, precisely the same as those on the main canal.

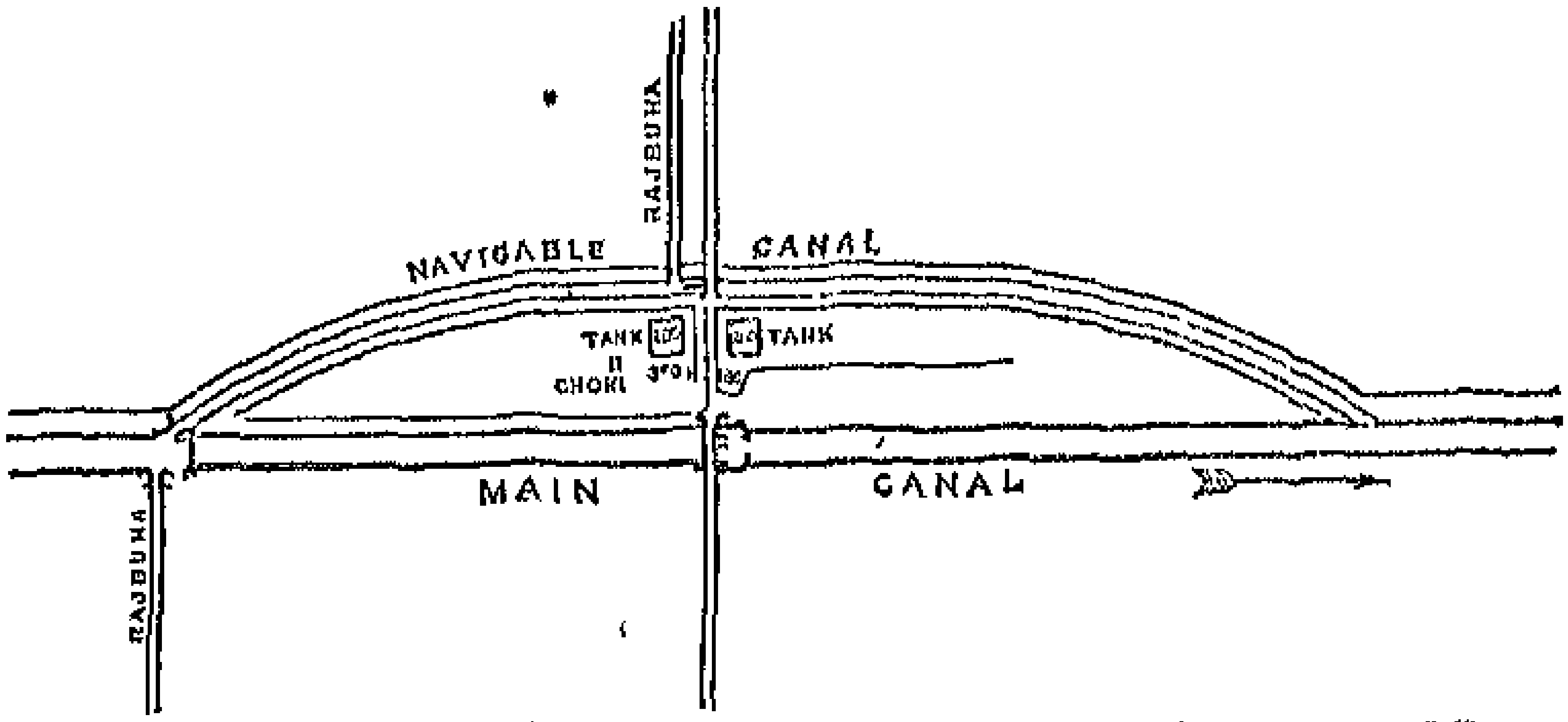
In the whole of these works a perfect uniformity of design has been attempted. With regard to height of gates, there are three distinct series, as shown by the above table. In other respects, every dimension in one work is identical with that of the other, and consequently the fittings which are adapted to one are adapted to all. The advantages, both to the supervisors and to the works themselves, of an economical arrangement of this sort are too well known to be dwelt upon with any extraordinary emphasis. They have, at any rate, been attempted to be carried out in all the designs of the Ganges Canal works, where varieties of dimension have been reduced to the smallest possible limits consistent with efficiency.

The two exceptions to the uniformity of detail in the earthwork before referred to, are confined to the navigable cuts at Muhmoodpoor and Bhola.

At Muhmoodpoor, the alignement has been retained in all its integrity, but in effecting this the channel came in contact with a good deal of low ground. A jheel or hollow of some extent was intersected, and for a considerable distance the true level of the bed was above that of the surface of the country. It became necessary, therefore, to embank that part of the channel which was connected with the low ground, and to make such arrangements for procuring earth for that purpose as would lead to the least disfigurement to the land in the neighbourhood. The following diagram will show the disposition of the works at Muhmoodpoor, the site of the tanks or reservoirs from which the earth has been taken to form the embankments, and the abnormal position of

the first-class choki dependent on the irregularity of the ground and the *island formed by the navigable cut.*

Diagram 123.

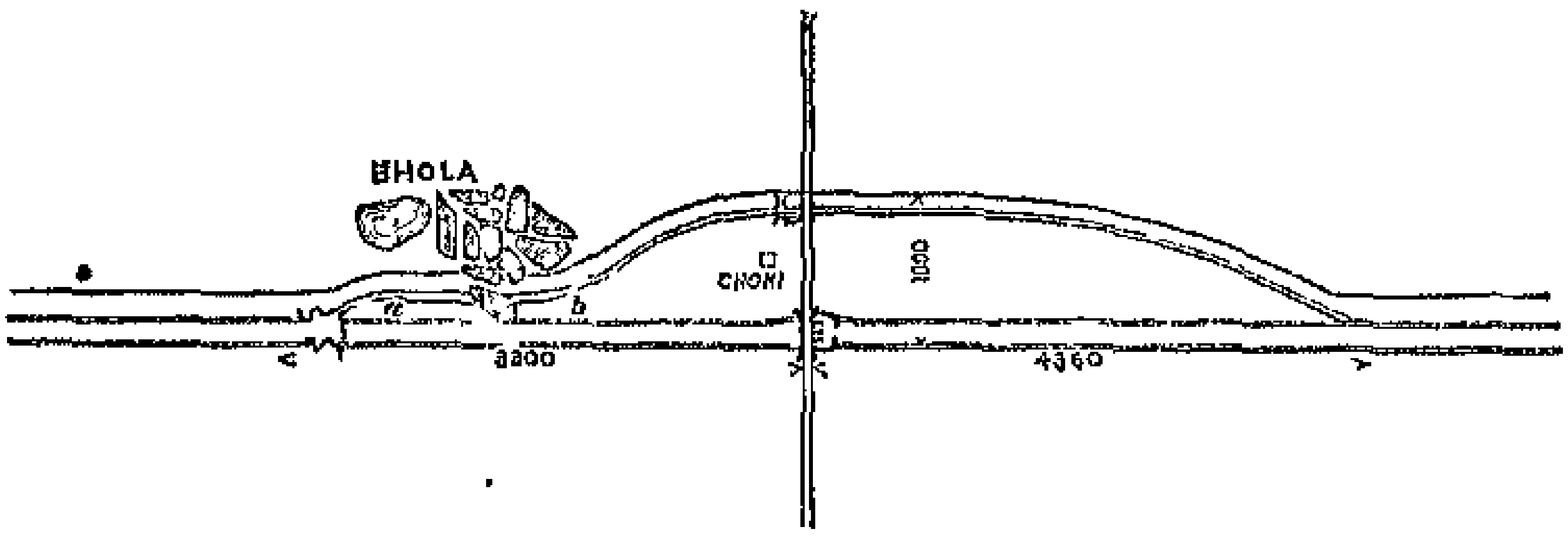


I consider that these reservoirs are a nuisance. They have been retained within the smallest possible limits, on measurement calculated on the required demand for earth. They have been dug as deeply as economy would admit of, so as to reduce as much as possible an area which will necessarily become a field of reeds and water-rushes: and everything has been done to render this nuisance as innocuous as it possibly could be. I am not without hopes that occasion may be found hereafter for filling in these reservoirs, should their existence materially affect the health of the station. This may demand a summary remedy, but it is possible that the clearance of the navigable channel from silt and sand deposits may in the course of time provide material in sufficient abundance for disposing of the evil without any necessity for specific estimate.

At Bhola, the variations from the general design are *dependent on the village, which is situated within a short* distance from the canal boundary. It would have been necessary either to enclose the village in the island, by carrying the navigable canal round it, or, by making certain modifications in the alignement, to keep clear of the village altogether. To have brought the village

within the boundaries of the canal would have been as annoying to ourselves, as it would have been inconvenient to the inhabitants. We should not even by doing this have maintained the alignement in the required form. The navigable cut would have been carried on a very extended circuit to meet the requirements of both parties, and, laying aside the additional expense, the advantages appeared to be in favour of the modified course, in which the village would meet with no interference. The plan, therefore, of the Bhola navigable cut has been laid out as represented in the following diagram:—

Diagram 124.



From *a* to *b*, the channel has been widened out into a harbour for boats, which is a convenient appendage to the navigation, and the earth which has been excavated from it has enabled us to equalize the surface of the ground in its neighbourhood, and to complete the embankments of the main canal which would otherwise have been imperfect.

In the construction of the masonry appended to the works on the navigable lines which I have thus described, bricks have been invariably used, with some trifling exceptions in the foundations at Sulawur, Bhola, Dasna, Pulra, and Simra, where the proximity of kunkur quarries has enabled us to adapt that material to the more massive parts of the structure. At the above places, Pulra excepted, the tail foundation walls have been laid upon blocks sunk to a depth of 12 feet, a necessity arising from the surface of spring-water showing itself within

the limits of the projected foundations. With the exception of the four instances above mentioned, the works have been laid in dry soil, and have been constructed without any difficulty. The works at Chitowra have been built entirely of small bricks, procured from the ruins of a large surai which was purchased in the neighbourhood.

The above includes the whole of the works which have up to the present time been built for the purpose of navigation, with the exception of those at the terminus of the Cawnpoor line, which will be the subject of a separate chapter. My estimate of 1850 includes other works of this description which have been designed for overcoming the changes of level on the Cawnpoor and Etawah terminal lines. It is anticipated, however, that the smallness of those changes of level will, in all probability, lead to a self-adjustment by a natural equalization of slope arising from the deposition of silt and sand, without any necessity for the introduction of separate works for navigation. The terminal locks into the Jumna on the Etawah line will, agreeably to the present plan, be postponed, until the progress of the works is further advanced, or until the disposition of the canal supply is fairly understood. These works are proposed to be similar in every respect to those which are now under construction at Cawnpoor, with the omission of those parts of the design which are expressly adapted to that particular locality. The Etawah terminal works will be restricted to a series of locks on the Cawnpoor plan, the total amount of descent from the upper to the lower levels being equally distributed in drops of a uniform perpendicular height. These locks will temporarily be unconnected by revetments; they will be accompanied, however, by the necessary buildings and reservoirs for navigation, as well as for mill purposes.

The main canal and its branches are, it will be understood from the description formerly given, fitted on their

whole extent with towing-paths, for the convenience of navigation. These paths are maintained uninterruptedly from one end of the canal to the other, either by pathways carried under the bridge waterway arches, or more commonly by passages in prolongation of the towing-paths themselves, made under the bridge roadways. In the *former case, the boats proceed in their progress* without any hindrance from the interposition of bridges; in the latter, the separation of the towing rope from the cattle on arrival at a bridge is indispensable. The plan which I propose to adopt is shown in diagram 125, where it will be seen that one of the bitt-heads connected with the rajbuha channel above bridge acts as the support for a chain with a buoy attached, the buoy floating below bridge. On the arrival of boats at the buoy, they are hooked to it, whilst the cattle and towing apparatus pass onwards through the passage. The boat people then either pull themselves onwards by means of the chain attached to the buoy, and then refix the boats to the towing ropes; or, should the boats be too heavy for this purpose, the towing rope is thrown to them from above bridge, belayed, and the towing upwards continued without the aid of the buoy chain. Facilities are thus given for the passage of craft both up and down stream along the whole of the channels connected with the Ganges Canal works.

It is hardly necessary to descant on the value that will be derived to the inland country especially, from the means of water carriage provided by the Ganges Canal and its branches, even in its most restricted sense. Admitting that, as a work specifically for irrigation, the canal will be liable during drought to a want of supply at its lower extremities, and to constant interruptions elsewhere, it will place the central districts, and the numerous towns and villages which lie on its course,

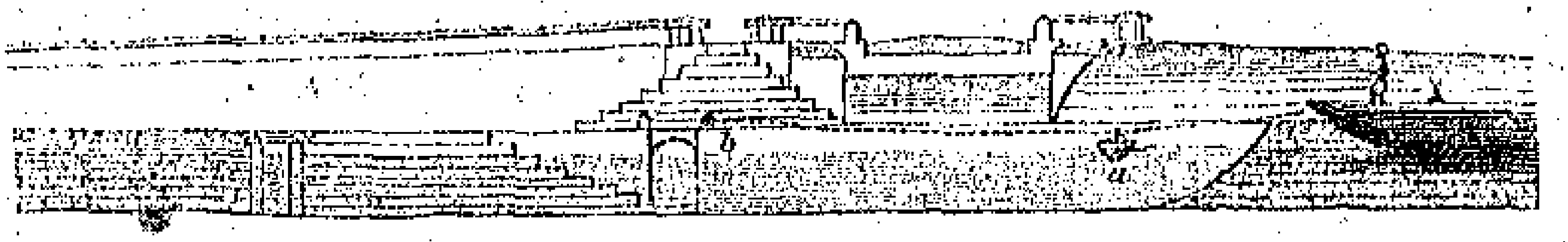
in immediate connection with mountain and hill produce; it will introduce a new species of commerce in the country through which it runs, and provide a supply of material for building purposes which at present is unknown.* Timber of all descriptions, rope, string, firewood, charcoal, and the numerous articles of mountain produce which are now, from *the cost of land carriage*, shut out from the country markets, will by means of this inland navigation be freely circulated. The above are some of the first, simplest, and most readily to be accomplished benefits that the canal will confer upon the country in its subordinate character of a navigable line. We may look, however, to the higher advantages bestowed *upon countries in general by* the *introduction of* water carriage. The transmission of heavy goods, the circulation of country produce, and the means of a cheap conveyance to the community, are all the necessary consequences of works of this nature.

Name of Work.	Total Cubic Content.	Cost of Masonry per 100 cubic feet. (RS. A. P.)	Cost of Stucco per 100 superficial feet.	Total Cost. (RS. A. P.)
Bahadoorabad No. 2.	83,396	17 9 7	Included in masonry rate.	15,807 3 2
Ditto. No. 3.	81,065	16 10 11	ditto.	14,701 5 2
Assoffnuggur . .	Not complete.	17 2 9	Not complete.	Not complete.
Muhmoodpoor . .	127,044	13 1 6	Included in masonry rate.	23,960 14 0
Belra	126,675	12 12 6	Rs. 3 15A. 9P.	18,100 14 10
Jaoli	131,507	14 13 6	Included in masonry rate.	21,927 1 8
Chitowra	141,537	11 6 9	3 13 9	18,153 11 8
Salawur	*Not complete.*	*11 6 6*	*Not complete.*	*Not complete.*
Bhola	147,444	14 12 10	Included in masonry rate.	24,174 13 2
Dasna	Not complete.	12 5 6	Not complete.	Not complete.
Pulra	*100,480*	*10 0 0*	*2 7 7*	*12,904 9 2*
Simra	105,443	10 0 0	2 7 5	13,204 15 3

The total cost shown above is exclusive of regulating apparatus.
The *Bahadoorabad locks* have no mills to them.

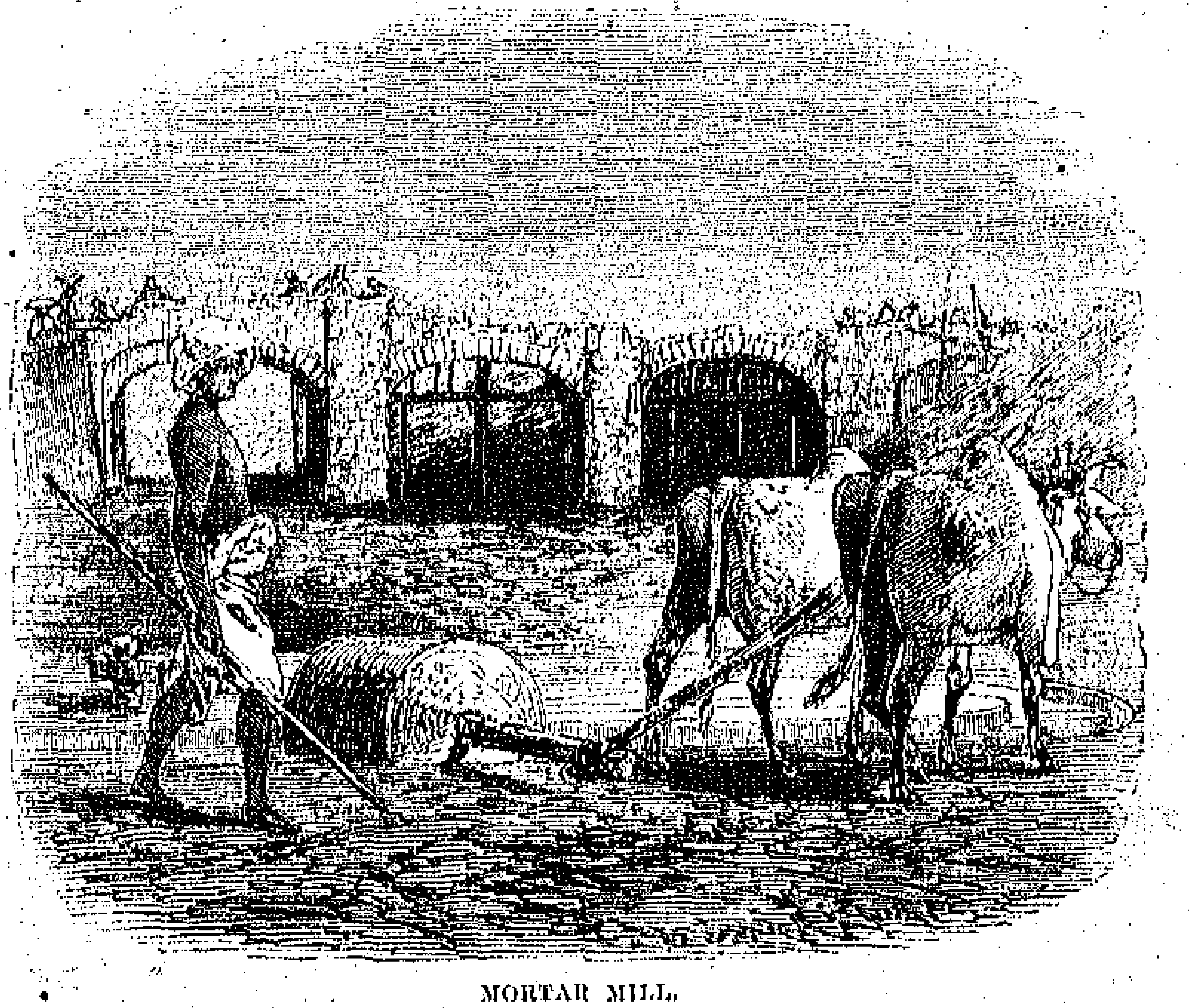
* In the central districts of Mynpoori and Etawah, the stalk of castor-oil plant is substituted for bamboos and rafters in the cottages of the poorer classes.

Diagram 125.



a. Buoy floating below bridge attached by a chain to a bitthead *b*, above bridge.

The total amount of masonry and the cost per 100 cubic feet of the different works attached to the locks and navigation cut-head works are shown in the preceding table; the works at Ranipoor and Puttri being omitted, as their cost is included in that of the super-passages, under which head it will be found.



MORTAR MILL.

CHAPTER VI.

WORKS OF DISTRIBUTION.

Section I. Rajbuha Channels and Earthwork.
Section II. Rajbuha Heads and Masonry Work.

THE whole of the design for these works has been so fully entered into in Part II., Chapter IV., that I need say nothing further here than that my object has been to avoid as far as possible any hasty proceedings in laying out the rajbuhas until the engineers could, by being relieved from the heavy works on the main canals, turn their attention undividedly to the subject. I was, moreover, desirous that my successor, whose attention has been directed to irrigation, and to the best methods adopted in Europe for distributing water for that purpose, should not be shackled or interfered with by any permanent works that might interrupt his progress. It is with this view that, although I have constructed all the heads for irrigation as connected with the main channel of the canal, I have made them of such a form and of such a capacity of channel that they can at any time be fitted to the requirements of modules or machinery for regulating the supply of water. It would be a mere repetition were I to describe the position and detail of these works, as a full account has been given of them in the chapter above alluded to.

I have in the above chapter entered fully into my

views as to the general system of the disposition of leading and feeder channels, and have shown how completely the tract of country which we are called upon to irrigate is commanded by the reservoirs of supply.

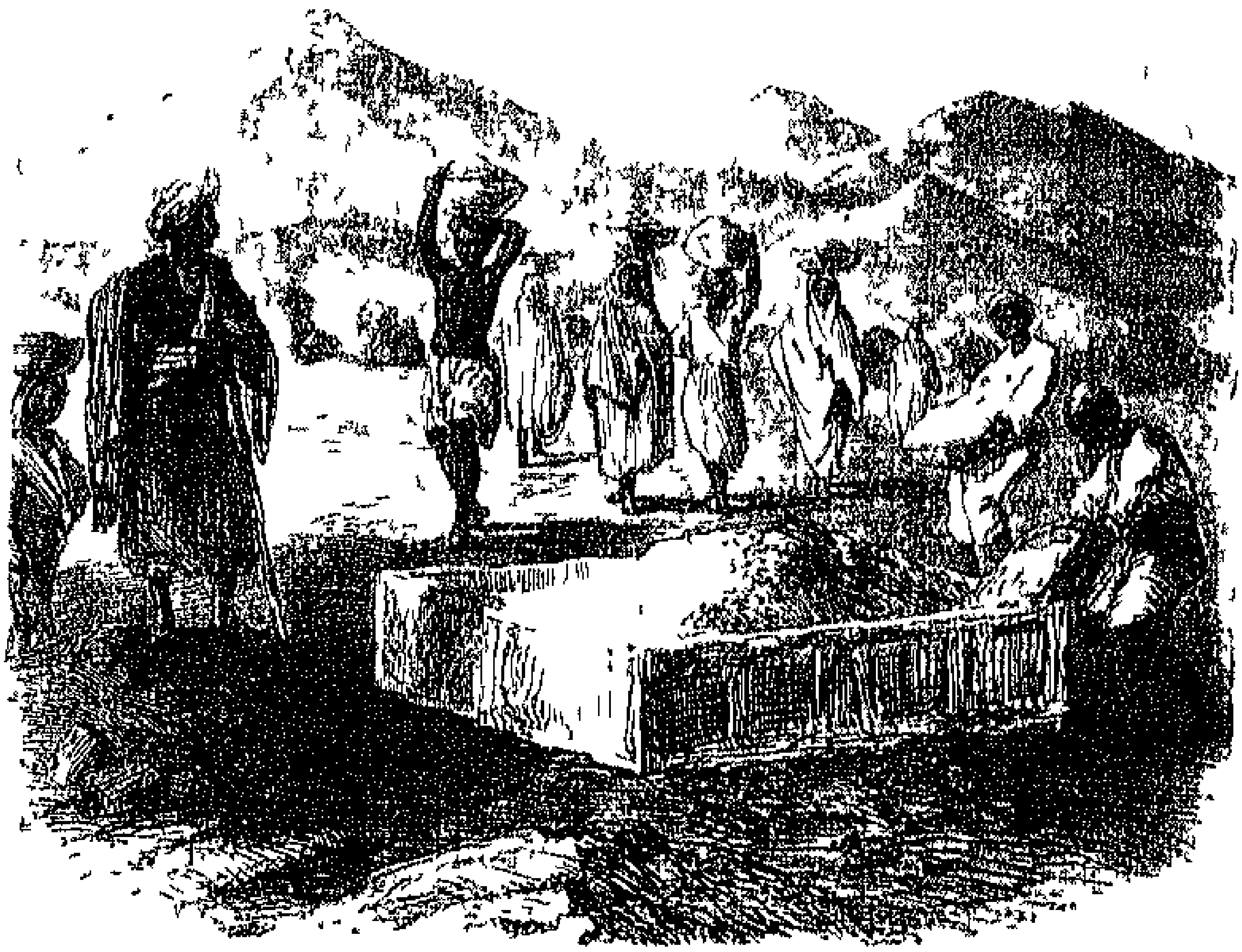
With the exception of the masonry heads, the greater part of which has been completed, nothing has been done in the excavation of rajbuha channels, excepting the laying out and excavation of a portion of the main lines on the right and left of the canal from the head of the Assoffnuggur Falls downwards. These were commenced early in the rains of 1853, and were in progress at the period of my resigning charge of the works in April, 1854. On the right side, 40 miles of channel had been completed; on the left, 36 miles. Material in considerable quantities had been collected, and the engineers were only waiting for a relief from the heavy works that were in progress on the main line, to carry out the rajbuhas with vigour. For this purpose a good deal of surveying and examination of ground was in progress in the Meerut and Bolundshuhur districts, under the supervision of Mr. P. Volk, in preparation for extending the main lines in prolongation of Mr. Read's channels, which are now in progress in the Saharunpoor, Muzuffurnuggur, and the upper part of the Meerut districts.

On the first section, therefore, a mere commencement has been made in the leading channels from the head of the irrigation on the high land of the Doab downwards. The work has been entirely done by contractors, who excavate the channel and complete the embankments at a rate of rupee 1-4-0 per 1,000 cubic feet. On the second section, which includes the masonry heads, bridges, aqueducts, escapes, &c., the heads only have been completed to an extent corresponding with the progress of the masonry works on the main trunk and

the terminal lines from Nanoon. This, however, includes the whole of the heads as far down as Nanoon, as well as those on the Cawnpoor terminal line; those on the Etawah terminal are finished or in progress as far down as the 110th mile of the course of the channel.

None of the other works are commenced upon, beyond the collection of materials and laying out the bridge and aqueduct on the Khutowli escape.

It will be understood from what has been said before, that the whole of the cost of the works connected with this chapter appertains to the zumindars. They are in all respects private undertakings, carefully laid out, and looked after by the canal authorities, but no further chargeable to the Government than in the advances of money made for their construction. For further information, however, on this and all other points regarding works for irrigation, I must refer to Part II., Chapter IV.



MEASURING SOORKHI

CHAPTER VII.

WORKS FOR MACHINERY.

THE heads under which this chapter may be divided are:—

Section I. Workshops and Machinery attached.

Section II. Mills for Corn-grinding.

Section I.—Workshops and Machinery attached.

Establishments for workshop purposes were necessarily leading considerations in commencing the Ganges Canal works, and buildings for the accommodation of smiths and carpenters were amongst the first to which the attention of officers was directed. The site of the dam and regulating bridge, where the canal channel leaves the bed of the Ganges River, is on the estate of Myapoor, in which there is neither village nor population, the land being farmed by the people of Kunkhul, a town of considerable importance in the neighbourhood. Close by the alignement of the canal right boundary, a serai, or enclosure, built partly of brick and partly of cut sandstone, with a pukka well near it, and at some distance an unfinished mundul, or Hindoo building, were the only marks of habitable settlement. The former was used for cattle, the latter was deserted. The serai, which in its external measurement is 130 feet × 98·5 feet, was readily made over by the proprietors on an annual rent of 50 rupees, and it was immediately converted into

a workshop. Its interior was conveniently adapted to the purpose. On two sides were covered rooms with verandas in front, extending on the full width of the quadrangle. On the other two were gateways; that on the north sufficient for the entrance of men and cattle, and having some pretensions to architectural character; *the south, or opposite side, being 11 feet in width, and* capable of admitting carts. With the additions of rooms for forges, &c., which were arranged on the flanks of the entrance, this enclosure became of the greatest use, and while the head-quarter station remained at Myapoor, was the leading workshop. Since then it has been used as a lock-up store-room, and it may be considered as an useful appendage to the works in the neighbourhood.

As early as 1843, and shortly after the Munglour division of the works had been established by Captain Turnbull, of the Engineers, the preparation of workshops on a more extended scale in the neighbourhood of the Solani River, and near the site of the aqueduct, was undertaken. The town of Roorkee, situated on the edge of the high land which skirts the Khadir, or low tract through which the Solani passes, was the point on which the aqueduct was directed. Its neighbourhood was marked by undulating ground, with knolls, many of which bore the marks of having been the sites of ancient villages. These were separated by raviny hollows, acting as drains or watercourses from the higher to the lower levels. The spot which I selected for the Roorkee workshops was on the highest of the knolls above described, and lying immediately on the left of the canal on its reaching the Bangor, or high land of the Doab. From the quantities of broken pots and crockery with which the surface was covered, this spot had been evidently the site of a former village. At some distance from it were the remains of Mussulman tombs. It was well adapted

to our purposes, and in its then uneven and irregular surface was capable of giving accommodation to an enclosure of 250 feet square. This enclosure was completed previously to my proceeding to England in 1845. Independently of the mere enclosure, the quadrangle was provided in its interior with accommodation for smiths and carpenters, in lines of arcaded rooms extending on its whole length on the east and west sides. On the former, offices of different descriptions, including an instrument and model room, were constructed on plans which accompanied the printed report of 1845. This quadrangle, and the accommodation above described, served its time, and became the nucleus of future buildings to meet the constantly increasing wants of the works. During my absence from India, from 1845 to 1848, although the interior of the quadrangle had received a further increase to its accommodation by the addition of arcaded rooms on the north and south similar to those which had been before built on the east and west sides, there were clear and unmistakeable signs that the accommodation was entirely insufficient. At this period, moreover, the earthwork on the aqueduct had arrived at that point when mere manual and basket labour had ceased. The earth required for the enormous embankments forming the line of aqueduct was now to be brought from the sides of the valley, and from a distance which rendered railroads and earth-waggons indispensable. For these purposes it became necessary to extend our workshop accommodation, and at the same time to improve our means by the application of machinery, and by the use of superior tools. A design for additional workshops in extension of those already built was therefore submitted to the Government, who at the same time made an application to the Court of Directors for the despatch from England of machinery

adapted to our particular requirements. I had when in England secured the services of a practical engineer, who joined me in the month of August, 1848, and about the time when the alterations which I have above alluded to were about to be commenced. Shortly before, or in the month of July, 1848, Lieutenant Augustine Allen, an officer in the 55th Regiment of Native Infantry, was appointed as an assistant to the executive engineer of the Northern Division, for the especial purpose of taking charge of the workshops; the designation under which he was appointed being "Engineer of the Timber Yard." The Roorkee workshops, therefore, began at this time to assume a more defined shape than they had done previously, and a system of order and method, with improved habits of conducting the manufacture of iron, and of carrying on the duties of the timber-yard, began to exhibit themselves in a very marked degree. No great step, however, could be made until the machinery had arrived from England, and until the increased accommodation which this, as well as the increase of workmen, rendered necessary, had been completed. The improvements and additions which were at this time made, consisted in separating the iron from the timber department, confining the former to the original quadrangle, and making a new enclosure in connection with it for the purpose of the carpenters. (In Plate LIX. of the Atlas plans of these shops are given in the fullest detail.) This new enclosure, which is a mere extension of the former one, extends as far south as the high road of approach to the Roorkee Bridge. It occupies ground which previously had been a great disfigurement, from its irregularity of surface. The filling in of the extensive hollows attending upon this irregularity enabled us to smooth off and level the whole of the ground on the east face of the quadrangle and fronting the model-rooms;

and the construction of the enclosure, in addition to giving space to the workshops, was one of the greatest possible improvements to a site which must otherwise have been not only ugly, but offensive, from the usual causes, which in the vicinity of native villages affect injuriously all ground of this sort. This enclosure, which is confined in its strictest sense to timber works, consists, like that of the quadrangle before described, of an open centrical area, surrounded by shops and warehouses resting upon the encircling wall. The shops are arcaded in open lines for the use of the carpenters; the warehouses differ merely in respect of their being fitted with doors and means for the protection of property.

It will be understood from the position of the quadrangle or iron yard, situated as it is on a high mound, that it is much elevated above the canal, which passes close by and parallel to it; sufficient distance having been left between them to admit of an extension to the buildings on that face. Here, therefore, or on the western side of the old enclosure of 1843, very extensive accommodation, in the shape of lathe-rooms, &c., has been built; the higher portion of the ground, or that on a level with the existing buildings, being occupied by engine, lathes, and machinery; that on the lower, which constitutes a basement (with an upper story), being devoted to furnace and boilers, with the sawing machinery. The upper story, which lies on the same level with the lathe-room, is occupied by the finer sort of smith's and carpenter's work. The façade formed by the above mass of building is in prolongation of the western wall of the timber-yard enclosure, and at a distance of 40 feet from the steps or ghats which line the aqueduct. Here it is intended to establish quays and cranes in communication

with the workshop yard. On the eastern face of the iron yard or quadrangle, and directly opposite to the buildings above described, the model department, which, as originally built, consisted of one room of $40' \times 20'$, has been increased by the addition of a room of equal dimensions placed parallel and connected with it by a wide aperture supported on each side by plain Doric pillars, isolated, and flanking circular headed niches formed in the wall. This large room is furnished with tables made of stone slabs, and is devoted entirely to models, to the library which occupies deep recesses placed in uniform positions in the room, and to pictures of either public works of great interest, or of men who have distinguished themselves in connection with them. This addition to the old model room led to a projection equal in extent to the size of the new building, in front of the original façade; this projection has been covered by a veranda or colonnade corresponding in character with that of the original work; its centre being occupied by a clock-tower, the basement or lower story of which acts as an entrance-hall or vestibule to the model rooms.

The building of the above works extended through some years, in so far that additions and improvements adapted to circumstances were constantly in progress. In 1849, however, the most necessary portion, including the lathe, model, and engine accommodation, was entirely completed, and in 1851 the machinery, which had been ordered and sent out by the Court of Directors, arrived at Roorkee. This consisted of the following:—

1 Ten horse-power condensing steam-engine, with boilers.
1 Large planing machine.
1 Drilling and boring machine.
1 Small drilling machine.
1 Punching and shearing machine.
1 Lathe, 12 feet.
1 Screw-cutting lathe, 8 feet.
1 Ditto ditto, 7 feet.
1 Steam arm.
1 Screwing machine.
1 Blowing fan.
2 Grindstones.

SAW MACHINERY.

1 Baulk-frame.	1 3-feet Circular-saw.
1 Deal frame.	1 2-feet Circular-saw.

No time was lost by Lieutenant Allen, aided by Mr. Murdoch, the practical engineer, in fixing the machinery, and in the month of May, 1852, the greater part of it was at work. For the delay that took place we are by no means responsible. By some mistake or other, the steam-engine which was sent out was adapted to boilers placed on the opposite side to which the buildings for them had been designed. It was therefore necessary to change the direction of the steam-pipe, the work for which could be done at no place nearer than Calcutta. This was a great loss of time, although it was economized, in a measure, by completing in the interim the different arrangements in the machinery-room. The shafting attached to the saw machinery, consisting of most unnecessary changes of motion, and complicated by these changes to a somewhat unaccountable degree, was condemned, and a simple and direct shaft was substituted. A number of minor objections were raised, all of which had to be corrected, and portions of the machinery itself from their weakness had to be strengthened, whereby time was necessarily occupied. The steam-engine was a serviceable one, and the machinery, although not of the best, being, as the practical engineer remarked, "made for exportation to the colonies," has been working ever since tolerably smoothly.

In addition to the machinery above mentioned, Mr. Murdoch, the practical engineer, set up a small two-horse power engine, which I had purchased many years before. This, with a new boiler (that I had brought from England for the purpose), was, up to the period of the large engine being fixed, very usefully employed in turning two lathes,

a grindstone, and a punkah, which worked over the heads of the men at the lathes. Being high pressure, and in all probability made twenty years ago, this engine was rather complicated in its parts; it was much worn and injured, and since the removal of the lathes to the room constructed especially for their use, has been laid aside. The lathes which were turned by the little engine were brought out by me from Holtzapfell's, from whom the following articles were received at Roorkee, almost simultaneously with the arrival of Mr. Murdoch, the practical engineer, under whom they had been selected.

1 Self-acting lathe, entirely of iron, 8 inches centre, for turning works, 6 feet long.
1 5-inch centre lathe.
(Both lathes being complete in all respects for every variety of work.)
Tools of various descriptions.

Besides the above, the following machines had been purchased for the use of the shops:—

1 5-inch foot-lathe by Holtzapfell.
1 5-inch foot-lathe, self-acting and screw-cutting, by Whitworth.
1 5-inch ditto ditto ditto ditto.
1 5-inch self-acting foot-lathe, by Whitworth.
1 small 5-inch foot-lathe with common T rest.
1 7-inch lathe.

So that, on the arrival of the greater batch of machinery from the Court of Directors, the shops were very fairly supplied with the means for carrying on any work that they were likely to be called upon to perform.

During the whole of the period above-mentioned, and from the date of Lieutenant Allen's joining the workshops, his attention had been most energetically directed to the manufacture of *tools*, with which previously the shops had been totally unprovided; he had also prepared a variety

of useful machines for simplifying work, amongst which I may enumerate the following :—

Steam-hammer.
Superior bolt-screwing tools for hand and machine screwing.
Punching machine.
Drilling machine.
Key-grooving machine.
Pumping-engine for supplying the premises with water.
Foundry tools.

And he had introduced amongst the native workmen a variety of improvements, not amongst the least important being the banishment of the excessive use of the file, and the substitution of chiselling. A great deal of useful practical improvements had also been introduced into the system of forging iron, and into economy of fuel. The fuel used is entirely charcoal, and the forges, previously to the introduction of the blowing apparatus, were worked by large bellows with hand levers, excepting in cases where the native forge was employed, where the blast is gained by leather bags, to which a nozzle is applied. These forges were entirely remodelled, and, without pulling down the building in which they were placed, they were, by a judicious disposition, brought in direct contact with the blast from the blowing machine, the adaptation of which to the steam-engine was greatly improved by Lieutenant Allen, who, as in the case of the saw machinery, changed a complication of shafts into a simple bearing on the main axle. This new arrangement of the forges gave additional room for working, improved the ventilation of the low arcaded rooms in which they are situated, and greatly economized space. The whole of the improvements that were made in connection with the setting up of the machinery, and with the reorganization of the material depending upon it, appeared to me to be very satisfactory.

During the above period, a brass foundry on a small

scale had been established. A weighing apparatus similar to that which is so frequently used at English turnpikes, where the value of the load is read off in a side room, had been attached to the floor of the main gateway through which loaded carts entered. A department of painters, for the purpose of graduating levelling rods, &c., had been organized; and saddle and harness makers carried on a very successful trade in making harness of descriptions, shoulder-straps for the barrow-men, together with the whole of the leather work required on an extensive board of works.

The shops, up to the year 1851, were employed entirely on the manufacture of articles required for the Ganges Canal works, which kept them fully occupied. Boats both of wood and iron had been made for the use of a navigable canal which since 1848 had been in constant use for the purpose of transporting boulders and building material from Myapoor and the branch of the Ganges in its vicinity to the Ranipoor and Bahadoorabad works. Numbers of earth-waggons had been made for the use of the Solani Aqueduct embankments, and for the supply of material from the brick manufactories in the neighbourhood. Fixings for rails, and the iron work necessary for keeping up this species of communication, had been in constant progress. The works at Dhunowri had also been supplied with both waggons and rails; and the numerous articles more especially in demand for sluices of dams, regulating bridges, and for all the emergent wants of the works in progress, had been carried on without interruption.

Early in 1851, the demand for both surveying and mathematical instruments at the Roorkee Civil Engineers' College raised a question as to the advisability or not of taking advantage of the Roorkee workshops in forming, in connection with it, a department for their manufacture

and repair. The extensive works in the North-West Provinces, and the demand that these works occasioned for instruments of all descriptions, appeared to point out the Roorkee College as an institution in which a depôt of instruments might be well maintained for the purpose of distribution. Roorkee, with its Civil Engineers' College, workshops, model department, and in the immediate neighbourhood of the most interesting portion of the Ganges Canal works, appeared to be in many ways more appropriate to the purpose of depôt, than the different ordnance magazines scattered over the country; whilst for repair, it was beyond all question more convenient than Calcutta.

It was proposed, therefore, that the mathematical and scientific instruments now in deposit in the different magazines should be collected into a well-regulated depôt at Roorkee. That a stock of the best instruments of all kinds commonly required, be maintained by regular supplies from England, and that these should be held *for sale, or for loan on the public service, under rules drawn up for the purpose and promulgated for general* information.

It was further proposed that there should be a workshop in connection with the depôt, for the repair of instruments procured from England, and for the manufacture of such as can be made in this country.

The plan was seconded by the following strong recommendations:—first, the great demand that existed for such instruments in the North-West Provinces and the Punjaub; second, the insufficient provision for their safe custody in the several arsenals, and the delay and risk attending their transmission to Calcutta;—and it was approved of with hardly a dissentient voice.

It was observed with regard to the establishment of this depôt at Agra, as the head-quarter station of the

North-Western Provinces, instead of at Roorkee, that the latter is in the neighbourhood of the great works now in operation or construction on the Ganges Canal, and, even when these are finished, that as works of civil engineering they will, in all probability, be the most interesting and instructive of any to be found in India. That a large body of scientific officers are there assembled, with skilful artizans, well-seasoned materials, and powerful machinery for working up those materials. That, moreover, at Roorkee, there is a large and increasing collegiate establishment, the pupils of which it is of much importance to render familiar with everything that concerns the instruments with which they will have to work. Agra, although the metropolis of the North-West Provinces, and the seat of the civil government, has none of these advantages; it does not even contain a superintending engineer, or any scientific officer, excepting the executive engineer of the division. Roorkee, it was maintained, had, on the contrary, the greatest facilities for carrying out the project. Lieutenant A. Allen, of the 55th N. I., in charge of the workshops, was peculiarly skilful in making and repairing instruments, and in training up natives to execute such work. Lieutenant Allen had already done much in this way, and his presence at Roorkee had obviated the necessity of incurring the otherwise unavoidable expense of bringing out from England a mathematical instrument maker. Much had been done even at this time in forwarding the progress of the manufacture of cheap and simple substitutes for such of the more expensive instruments as could be made up easily in this country, and come within the means of native workmen. It was clearly desirable that the efforts which had been thus irregularly and desultorily put forth, should be reduced to order, and systematically exerted.

The delay and annoyance that had been experienced

in the adjustment of the steam-engine, in consequence of our inability to obtain a casting, so as to direct the steam-pipe upon the boilers, and to remedy the defect of the machinery as received from the maker, brought prominently to my notice the necessity that existed for making an iron foundry a portion of the workshops. The case alluded to is worthy of recording, as an example of how a mistake, where there are no means present of remedying it, may disarrange plans and delay progress. In the present case, the steam-pipe, which ought to have had its bearing upon the boilers which were placed on the left of the steam-engine, had it on the right, so that without an alteration of the direction of the pipe on its leaving the cylinder, the machine was useless, unless the building had been remodelled to adapt itself to the engine. All that was required was a short bit of pipe, with a bend or shoulder in it. This, had a foundry been present, might have been made in a few days. Here, on the contrary, although no time was lost in writing and sending drawings to Calcutta, we did not receive the article required until a period of four months had passed. We had, in fact, to send to a distance of 1,000 miles to get a thing that might with ease have been made at Roorkee, had a foundry been in existence. This, although the first and leading inconvenience, was only one out of a great many which gradually showed themselves as the workshops advanced. In a letter which at this period I addressed to the Military Board, it is observed, in drawing attention to the above circumstances, "I am by no means anticipating the wants of even our existing works in suggesting that no time should be lost in establishing an iron foundry at Roorkee. We require the presence of a man who is acquainted with the art; but beyond this, and the construction of the necessary buildings, I do not imagine

that the addition of the foundry to the yard would lead to any extraordinary expense, whilst it would give us the means of supplying ourselves at once with articles which we now at a great cost of time and carriage have to procure either from England or Calcutta. In a late instance, instead of being able at once to supply ourselves with a portion of steam-pipe, we have been forced to send a commission for its manufacture to a foundry situated at a distance of 1,032 miles from Roorkee. With reference, however, to the higher advantages and to the more general application of these workshops to the supply of the provinces with ironwork, whether forged or cast, it strikes me that the sooner the foundry arrangements are entered upon the better. The whole of the provinces might, in my opinion, and ought to be supplied with iron bridges, roofs, castings, &c., from Roorkee; and whilst Calcutta is the centrical point for the Lower Provinces and Bengal Proper, Roorkee would be more centrically, as well as more conveniently, situated for the provinces in the north. In conclusion, I may observe, that even with reference to the cost of English iron as far north as Delhi, and the fact that we can at present procure that material at Roorkee at a cheaper rate than we can native iron from Gwalior, I am by no means satisfied that in the extensive distribution of iron mines throughout the mountains in immediate approximation to Roorkee, we may not, through a well-appointed agency, open out an entirely new market for iron, and turn to useful account one of the neglected ores of the Himalaya Mountains."

The establishment of workshops and foundry at Roorkee, a place which was situated within 15 miles of the Sewaliks, and 40 miles of the Himalayas, would, it was supposed, bring into activity any dormant claims that the mines in the Himalayas might have upon the

attention of metallurgists. With forests to supply charcoal, and mines to supply iron, the Roorkee foundry would be independent in its own resources, whilst the clays and earth which abound, especially in the Sewalik Mountains, would be a fruitful field of interest in the manufacture of pottery.

The whole of the above views were adopted by the authorities without any demurrer, and having ultimately been approved of by the Court of Directors, they were ordered to be carried out as early as possible. The delay that has occurred in promptly acting on instructions which were asked for with such eagerness, arises from the great extent of the works both on the canal and college, which has up to the present period absorbed every brick as well as every labourer that could be collected together. From this cause, the extension of buildings necessary for the foundry and other purposes has been most unwillingly placed in abeyance, at least so far that the new buildings have only been carried on as material and opportunity offered. The designs, however, have been well matured, and progress, although slow, has not been altogether stopped.

The correspondence on the subject of this extension of the workshops, which commenced in July, 1850, and which had closed in the approval of the Court of Directors to the whole of the schemes which had been recommended, led to the following arrangements, which may be best explained in the words of a minute dated the 18th December, 1851, and submitted by me on the closing of the correspondence :—

"1. As introductory to the following memorandum, it may be better to explain the views which I hold as to the Mathematical Instrument Department as connected with the general workshops at Roorkee. I believe that these views are the same as those explained in Mr.

Secretary Thornton's letter to the Military Board, No. 398A of 1850, dated the 29th July, 1850, on this subject; but as the whole of the scheme depends upon a proper understanding of the wishes of the Government on this point, it is as well to explain my reading of them.

"2. The Civil Engineer's College at Roorkee is to be the depôt for serviceable instruments, astronomical, topographical, meteorological, and mathematical. It is to be under the control of the principal of the college for the time being.

"3. All instruments the property of Government, now deposited in store in the magazines or elsewhere, are to be transferred to this depôt, and a supply of those in most common demand is to be maintained, not only for the use of those employed on the public service, who will *obtain them under certain regulations to be hereafter* defined, but for the public generally; instruments being held available for sale for ordinary scientific operations, and for the equipment of individuals, whether publicly or privately organized for scientific purposes. The prices are to be regulated by the actual cost upon the office books. Barometers and other instruments for meteorological purposes, which are now obtained with such difficulty, and for the want of which so much *valuable information has been lost*, will, by *those means*, be always available. Roorkee, moreover, is so conveniently situated to the Himalayas and to the most interesting portions of our Indian territories, that a depôt at that place, offering facilities for the supply of instruments, is especially valuable.

"4. The mathematical department of the Roorkee workshops will be confined entirely to the manufacturing and repairing of instruments for ultimate deposit in the *depôt. All instruments received from the magazines or*

elsewhere, will pass through this department previously to their being lodged in the depôt. Its control will be vested in the superintendent of the workshops, whose transactions with the principal of the Civil Engineer's College, as the officer in charge of the depôt, will be *conducted in the usual official form of correspondence* and record.

"5. It is understood that by keeping the 'depôt' and 'department of manufacture and repair' distinct, and under the management of officers independent of each other, the instruments will undergo separate scrutinies both in workmanship and adjustment; both of them tending to insure the great object of maintaining a supply of efficient and standard instruments ready for immediate use.

"6. The college, therefore, being understood to be the 'depôt,' and the workshop the 'school of repair and manufacture,' I now proceed to the subject of this memorandum, viz., *the institution of the* Roorkee workshops.

"7. The workshops at Roorkee would, under a comprehensive plan for making them generally useful in the North-Western Provinces, consist of the following departments:

"1. Iron and Wood for general purposes.

"2. Mathematical Instruments.

"3. Foundry.

"8. I would place the whole under *charge of one* individual called the 'Superintendent of the Roorkee Workshops;' his salary would be 500 rupees per month, with an office establishment. As an executive officer, he would open an account with the Accountant-General North-Western Provinces, and his duties would be carried on under the direction of the Director of the Ganges Canal Works and the Superintendent of Canals North-Western Provinces. It is indispensable that the executive

engineer in charge of the works in the northern division of the Ganges Canal should have unlimited power in procuring the aid of these workshops, and that calls from the executive engineer should be attended to in preference to all others: should this not be admitted, or not carried out to its fullest extent, the executive engineer must necessarily fall back upon his own resources, and establish independent workshops for his own supply.

"I. IRON AND WOOD FOR GENERAL PURPOSES.

"This department would consist of the present iron and timber yards, in which ironwork for roofs and suspension-bridges, &c., timberwork of all descriptions required in the department of public works, and the general manufacture of all articles of both iron and wood required in the different departments of the service, would be undertaken.

"10. The iron-yard would contain warehouses for the maintenance of a depôt of hardware, such as tools, locks, keys, hinges, nails, and other articles used in the department of the public works. I would not restrict the sale of these articles to the public departments of Government, although these departments as a general rule, and when there was a deficiency in store, should have the preference. One great object that I would have in view would be to hold out to the people of the country a supply of wares of a superior description to those made by themselves; to introduce amongst them, at prices which would be remunerative, tools of a superior description, and to put them in the way of not only (by inspection of the shops) observing the European method of working, and judging of its superiority or otherwise over their own, but of possessing by purchase the means of imitating us, and advancing in a parallel course of improvement. In illustration of this object, I may men-

tion that a large supply of handsaws, which were procured from England for the purpose above-mentioned, has been disposed of, and articles of a similar description are in eager demand by the native carpenters. I would also observe, that the distribution of stores of this description would keep up a healthy circulation in the depôt. It would prevent that accumulation of old and obsolete material, which, I am given to understand, exists to a great extent in the magazines of this Presidency, and which, in the shape of the very articles which I allude to above, did exist up to a very late period in the warehouse of the Executive Engineer of the Cawnpoor Division of Public Works. In the case of the magazine stores, public sales at distant periods relieve the warehouses from lumber and refuse material, but at an enormous sacrifice to the State; whereas, had the articles not required been disposed of from time to time by private sale, the objects to which I have above alluded, and on the advantage of which I place so much weight, would for a long series of years have been in steady progress.

"11. The military board, in their letter to the Agra Government, No. 3,700, of the 5th of August, 1851, have, in pointing out that all the kentledge now lying in the magazines might be advantageously collected at Roorkee, gone very far in approving of the Roorkee shops becoming the centrical depôt of store and supply. It strikes me that, with the exception of articles strictly appertaining to the military and artillery branches of the service, everything now in those magazines lying within a reasonable distance might with advantage be sent to Roorkee; which as a civil board of works connected essentially with education, and established for the purposes of supply and distribution, would turn to better account the stores now in course of receipt on indent, and would be better able to dispose economically of the

old stores, than were they sold by public auction at the periodical magazine sales.

"12. The 'timber-yard' would in the same way act as a depôt for wood of all descriptions, especially saul (*Shorea robusta*); and the proximity of Roorkee to the Sewalik forests, as well as to the Himalayas, would extend the benefits of this yard as a wood depôt, by enabling the superintendent to keep up a supply of many useful hill articles, especially woods which are at present little known, and whose value is (from the difficulty of obtaining them, and in many cases from the ignorance of their existence) less appreciated. A true box (*Buxus emarginatus*) is easily procurable from the neighbourhood of Landour; it appears to be of excellent quality, and is likely to be serviceable to the wood-engraving department of the college. Both tar and turpentine from the pinus longifolia (*cheer*) of the Sewaliks are to be made with the greatest ease, and, as unadulterated, are more likely to offer a better and a cheaper supply than those imported for the magazines. Cordage materials, resins, dyes, and an infinity of materials, useful in both arts and manufactures, might be brought into general circulation through the medium of this depôt.

"13. The connection between the Ganges River at Hurdwar, and the workshops by the Ganges Canal, would, by giving the means of floating down rafts of timber, enable the depôt to be supplied with a variety of woods from the interior of the Himalayas. Deodar, ash, walnut, and woods indigenous to the temperate climate of the interior, might by these means be collected at Roorkee. By an economical distribution of time and labour also, these rafts might carry supplies of cordage

* During my superintendency of the Eastern Jumna Canal, a tar manufactory was constantly at work at the mouth of the Kaloowala Pass of the Sewalik hills.

material, and I have no doubt that at a very early period, a correspondence having been established between Roorkee and distant points in the Himalayas, numerous *products would come to light which at present are unknown.* I might here allude to the great variety of clays, many of them I have no doubt available for pottery and for other uses, which exist in the Sewaliks and in their neighbourhood, and to the advantages that we should derive from the presence of an officer with the talents and energy of Dr. Alexander Hunter, of the Madras Medical Service, whose researches in the natural resources of his own presidency, in doing honour to himself, and to all whom his example has carried with him, ought to stimulate us not to be behindhand in a field, I have no hesitation in saying, of equal, if not greater importance than any in the British possessions of India. *To carry this subject further would be foreign to the* object of this paper; but the Industrial Exhibition and Dr. Royle's pamphlet on the proposed contributions from India will, to all who are interested in rescuing the natural products of a large extent of country from their present obscurity, show what an active agent the Roorkee workshops may become, in not only doing this good work towards the Himalayas, but also to the provinces of Upper India.

"II. MATHEMATICAL DEPARTMENT.

"15. It having been decided that the depôt for surveying and mathematical instruments should be attached to the college, and that the manufacture and repair should be a separate department of the Roorkee workshops, we have merely to take into consideration the best means for carrying out the latter object.

"16. This object has been described in the Honour-

able the Lieutenant-Governor's Minute, dated the 21st of May, 1850, as follows:—

"'(i.) *The manufacture of instruments in common use, and generally made up in this country, levelling staves, perambulators, chains, plane tables, tripod stands, &c. The invention and formation of cheap substitutes for expensive machinery: e.g. common carpenters might make up plane tables, quadrants, and levelling instruments, which would enable an ingenious man to observe with a considerable approach to accuracy both horizontal and vertical angles: water or T levels for levelling; giving a large scope for ingenuity in popularizing the materials for scientific research.*

"'(ii.) *The repair of surveying and mathematical instruments.*'

"17. With reference to the first item, without discussing the advantages that would be derived from maintaining a depôt of articles as enumerated above, both by the canal officer and the civil engineer, the simple fact of readily supplying the one with levelling staves, or the other with chains, would gain their sympathy. Levelling staves on Gravatt's plan of graduation are now made by Lieutenant Allen in a manner equal to any that could be turned out of a London shop. Chains are also made equally well, and both these articles have the advantage of being graduated and compared with a standard. Of the facility, therefore, for carrying out this first object of his Honour's Minute, there can be no doubt whatever.

"18. The difficulties in which an officer is placed in these provinces from the want of the means of having instruments repaired, has been well pointed out by Colonel Everest, in the preface to his last work on the Indian Meridional Arc. Colonel Everest has shown what can be done by a man of skill and intelligence,

who, when perfectly acquainted with its construction and value, finds himself in the midst of a wilderness, with an instrument almost hopelessly broken or disarranged: a circumstance to which he is perpetually liable. It is in getting rid of difficulties of the sort alluded to that the Roorkee shops will be useful, and it is hoped that, by an institution similar to that now proposed, these provinces, remote as they may be from either the metropolis of India or from the skill and manufactories of Europe, may hold within themselves the means of not only repairing, but also of making instruments.

"19. The *making* of instruments, however, is a question upon which a few remarks may be necessary. It is not presumed that the mathematical department of Roorkee will, during the present period, or even for many years, compete with Europe in making the more complicated apparatus attached to the astronomer's observatory, nor could it pretend even to a competition with the professed mathematical instrument maker, either in the best description of surveying circles, or in the instruments attached to the drawing department. I believe that, even were the Roorkee shops provided with efficient men, it would take some time before the complicated machinery necessary for the manufacture of articles in large quantities, would enable them to compete with the English market. Every one who is acquainted with the extraordinary patience of the native artificer, the delicacy of manipulation which characterizes his handiwork, his capacity for observation, and his powers of imitation, will agree with me in appreciating the value of the material that we hold for progressive improvement. Without any great stretch of enthusiasm, I may predict that we shall not only be able to compete with Europe in the quality, but (from the cheapness of native labour) undersell it in

the prices of instruments. I consider that the present engineer of the shops is peculiarly qualified to carry out the objects of the Lieutenant-Governor's minute; and if he is allowed the encouragement that I would propose to give him, the progressive advance which is alluded to above will, in all human probability, be certain.

"One of the first articles which would be necessary for the purpose of instrument making, is a dividing apparatus, which might be procured from England. Should there be any difficulty thrown in the way, I am satisfied, and in this am borne out by others, that a short time only is required to provide ourselves with one of our own making. It is very satisfactory to me to be able to place this opinion on record; but I do so in perfect confidence that I shall not be mistaken. The cost of an apparatus of the sort above-mentioned may be, I understand, about 10,000 or 12,000 rupees.

"Additional and separate accommodation will be required for this department, although such arrangements are proposed to be made as will ensure compactness, and place the shops which are specifically for mathematical-instrument purposes, in immediate connexion with the general shops.

"Lieutenant Allen, with whom I have consulted, and who is cognisant of the contents of this memorandum, considers that two main rooms of the following proportions are indispensable:

1 Finishing-room for metal work, 70′ × 20′.
1 Carpenter's and blacksmith's workshop, 100′ × 20′.

These, with small rooms attached, may be easily gained by additions and alterations in the immediate neighbourhood of the engineers' office room in the existing buildings. They must be upper-storied rooms, and this may

probably lead to expense in the necessary modifications for adapting the present lower stories to a superstructure for which they were not intended. I do not think that the cost can be estimated fairly at less than 5,000 rupees; it may, however, be less; Lieutenant Allen considers that 3,000 rupees will cover the whole.

"I would endeavour to make it understood, that the means at our disposal in the general workshops, described as iron and timber yards, will be available for the mathematical as well as for the foundry department, the whole being one institution and controlled by one head. The mathematical instrument shops, however, will require certain specific appointments; and the following articles may in a general way be considered indispensable:—

2 Travelling mandril lathes . . . . (say)	£60
1 Set of taps and dies similar to those used by Messrs. Troughton and Simms	50
Grinding and polishing apparatus, polishing powder, &c.	45
Small tools, table-vices, drills, saws, &c.	75
Small Stores.—Materials and parts of instruments ready made, with a view to more immediate repairs, particularly of instruments to be received from the magazines, viz., object-glasses, brass tubes, steel and brass wire, sheet brass, &c. &c.	80
	310
Cost of carriage, &c.	80
Grand total	£390

Or say that a sum of about 4,000 rupees will be required for original outlay on these articles.

"Lieutenant Allen considers that, in the more important division of establishment of artificers, viz., the workers in metal, five men, possessing the requisite skill, might at this moment be obtained from the workshops, and that an equal number might be collected from the provinces, who, after a little instruction, would be fully

capable of working in the mathematical instrument department, but the training of an efficient establishment will require time, and the amount of work undertaken must be proportioned to the growth of the establishment.

"Lieutenant Allen, however, suggests that the following scale of establishment may be adequate, when fully trained, for the performance of the work required for the first few years:—

SMITHS.

	RS.	
1 Mistry at 30 rs. per month	30	
2 Smiths at 20 "	40	
4 " 15 "	60	
6 " 12 "	72	
6 " 8 "	48	
12 " 6 "	72	
5 " 4 "	20	
		342

CARPENTERS.

1 Carpenter at 16 rs. per month	16	
6 " 12 "	72	
4 " 8 "	32	
		120
Total Co.'s rs. per month		462

Both as regards amount of salary and numbers of individuals employed, the appointment of the above people would be progressive. Remarkable instances of skill and talent ought, however, to be rewarded and secured at a higher payment than is noted in the above scale; and I *would give every encouragement by increase of salary, to* those who obtain from the engineer of the shops a certificate of the highest qualifications. I would, moreover, to men of this description, hold out a periodical increase of salary, say at the termination of every five years of service, on any table of rates that might be determined on. It is the utter want of prospect in the present system, that prevents us from obtaining the services of

educated men, who, on the first opening in another department leave us to better themselves.

"As above described, the mathematical department would lead to the following expense, say—

	RS.
Buildings	5,000
Tools	4,000
Dividing apparatus	11,000
Total Co.'s rs.	20,000

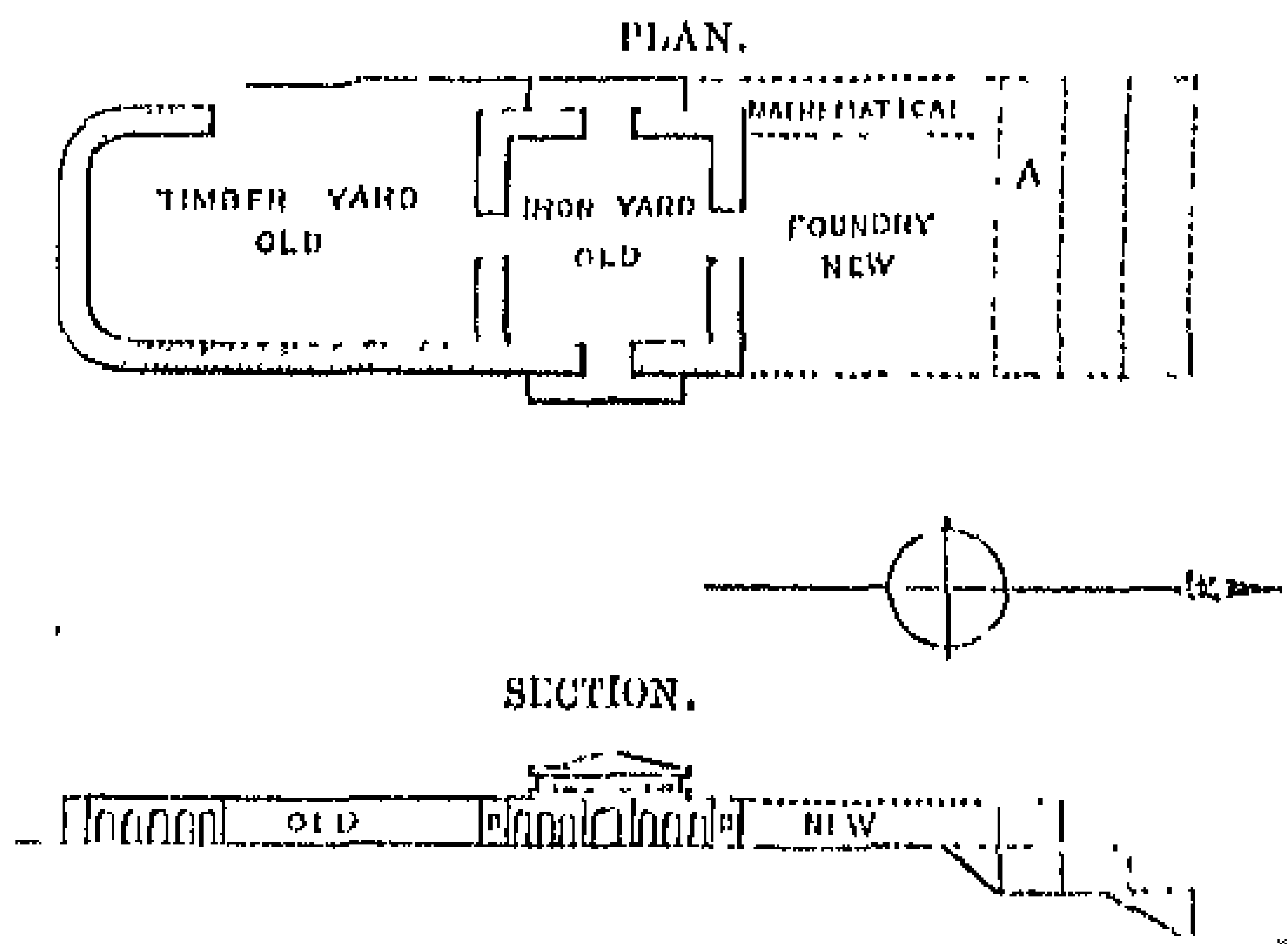
with a monthly establishment amounting to Company's rupees 462.

"III. FOUNDRY.

"I have in the list of establishment included that which may be required for this branch of the workshops; but as I consider that the economical value of a department of this sort depends entirely on the adoption of both the metal and fuel which are available in the neighbourhood, and not in the importation of European products, whether iron or coke, I would commence operations on a limited scale. I would recommend that the planning and lining out of the workshops should be designed on an anticipated establishment of a foundry, and in the meantime I would prosecute all inquiries as to the nature of the iron to be procured from the Himalayas, and from the mines to the westward of India; as to its cost on delivery at Roorkee; and as to its comparative merits, both practically and economically, with the iron in use elsewhere. I have begun to collect specimens of the different iron ores and metals of the Himalaya districts, and, in connexion with the Museum of Economic Geology at Roorkee, to form a valuable groundwork for analysis and experiment. A great deal may be done by degrees in carrying out this examination, and practical experiments may be made in the use of charcoal as fuel for the purposes of a foundry.

In smelting iron, charcoal is extensively used in different parts of India, and up to the end of the last century was very generally used in England. Its value for casting rests more on its economical results than in its insufficiency for the purpose. I have in a diagram below shown the position that a foundry would hold on the workshop premises: it would constitute a completion of the buildings, as connected with the mathematical, and those for other purposes on the northern face of the present enclosure.

Diagram 126.



"The dotted lines show the position of the foundry with the mathematical instrument buildings on the west. Others for general purposes on the north extend over the deep descent of the ground, as shown in the section. I would occupy the line at A with quarters or rooms for the accommodation of the practical engineers and Europeans attached to the workshops, the presence of whom near at hand, experience has shown to me to be of the greatest value. The lower stories gained by the peculiar features of the ground, would enable this sort of accommodation to be managed very satisfactorily. The design drawn out in detail can, if necessary, be submitted hereafter; but I should estimate the cost of the whole of

these additional buildings, not including the mathematical shops, to which I alluded before, at under 10,000 rupees."

The following table exhibits the amount of monthly establishment that was proposed in the above memorandum:—

" SUPERVISION.

	RS.
Superintendent of workshops	500*
Deputy superintendent of workshops	300
Total	800

ENGLISH OFFICE.

1 Book-keeper	150 to 200
1 Assistant book-keeper	120
2 English writers at 40 rs. each, or 1 at 50 rs. & 1 at 30 rs.	80
4 Chuprassies (1 at 6 rs., 3 at 5 rs.)	21
1 Sweeper	4
Total	425

NATIVE OFFICE.

1 Native assistant	50
1 General storekeeper	20
3 *Mootsuddies*	24
1 Invoice and despatch-keeper (Iron yard)	15
1 Do. do. (Timber yard)	15
Total	124

IRON YARD, INCLUDING MATHEMATICAL DEPARTMENT.

1st Foreman	Practical men.	250
2nd Do.	Practical men.	200
3rd Do.	Practical men.	150
1st Mistrie		30
2nd Do.		30
3rd Do.		16
4th Do.		12
2 Smiths at 20 rs. each		40
4 Do. 15 "		60
8 Do. 12 "		96
8 Do. 10 "		80
20 Do. 8 "		160
36 Do. 6 "		216
36 Do. 5 "		180
20 Labourers at 4 "		80
Total		1,600

* With marching allowance.

TIMBER YARD.

	RS.
1st Foreman (Assistant-overseers)	90
2nd Do. ditto	70
1st Mistrie	25
2nd Do.	16
3rd Do.	14
4th Do.	12
6 Carpenters, at 12 rs. each	72
15 Do. 10 „	150
20 Do. 9 „	180
20 Do. 8 „	160
20 Do. 7 „	140
20 Labourers at 4 „	80
Total	1,009

FOUNDRY.

1 Foreman
1 Assistant foreman
1 Head mistrie
4 Assistant mistries
2 Carpenters
6 Labourers, stokers, &c.

"The preceding list includes all the establishment that will be required in the office, iron and timber yards, and the mathematical department. I have included the mathematical department establishment in the general list for the iron yard, as the employment of the whole is of one nature; the detail of the establishment for the mathematical department was given before.

"IV.—WORKSHOP OFFICE.

"*Superintendence.*—The duties of the superintendent and deputy are of a highly responsible nature. To high acquirements as mechanical engineers must be added the habits of order and system, which will enable them to take charge and regulate the distribution of stores of every description attending upon the shops. I would, if possible, select covenanted servants for these appointments; but in the difficulty of procuring men of this class, I would endeavour by a liberal salary and treat-

ment, to obtain the services of professional men from Europe. The superintendent would, of course, have the control of the whole, but the deputy who serves under him would, under the plan that I propose, be specifically in charge of the mathematical department.

"Their salaries as covenanted servants would be:—superintendent, 500 rupees per month, with 100 rupees marching allowance; deputy superintendent, 300 rupees per month. The marching allowance of the superintendent is intended to cover charges for inspection of timber-cutting in the forests, and works of that nature, to which his attention will be frequently directed.

"When uncovenanted servants (professional men) are employed, their salaries might be left for adjustment at the period of appointment.

"*English and Native Office.*—It will be understood from what has been said before, that the institution of these shops will entail upon the superintendent the charge of not only an immense quantity, but of a most varied description of machinery, implements, and stores, the responsibility of which, both in receipts and issues, will rest with himself. It is my opinion, therefore, to prevent disappointment of any sort, and to give the superintendent fair play, he must have at the head of his office a first-rate book-keeper. The necessity of having a man of this sort is evident. The appointment is one, in fact, that is intended to relieve the superintendent from the drudgery of detail, and to place him in the same position, and to give him the same advantages in his immediate engineering duties, which the Commission for the Department of Public Works contemplated in relieving the executive officers of works from their duties as accountants. To obtain the services of a man of this description it might be necessary to offer a higher salary than is now accorded to accountants of divisions; and to retain

his services, I would hold out to him a periodical increase of salary. The salary might commence at 150 rupees or 200 rupees per month, agreeably to the qualifications of the individual, with an increase of 50 rupees a month at the end of every five years of approved good service. Increase to be authorized by the Government on certificate from the superintendent of the shops. The assistant book-keeper or accountant would naturally look to the higher appointment for promotion.

"The two English writers would consist of one for the iron and timber yards, and one for the mathematical department. The Native Office does not, I imagine, require any explanation. The head native assistant would control all the native accounts and proceedings in the yard, with one general storekeeper, and two invoice and despatch keepers for the separate departments of the iron and the timber yards.

"The three mootsuddies would be used in detached duties, and in paying workpeople. These men would also look for promotion to the higher appointments. The chuprassies and sweeper could not be dispensed with, the former for the superintendent and deputy, for messages and other purposes, the latter for the cleansing of the office and rooms.

"After a careful examination of ther otarns and duties of these shops, I do not think that the above office establishment could possibly be placed on a lower footing. I beg, however, to lay great stress upon the presence of an efficient book-keeper, without whom there will be neither order nor regularity. It is, moreover, economy, to make liberal arrangements for an office of this sort, upon which so much of our success depends.

"The list of establishment submitted for the iron and timber yards is supposed to meet the wants of the shops, if kept at work up to the full means allowed by the

machinery and extent of the forge and shop accommodation. The entertainment of the members of the different grades would be a gradual process, and would not be acted upon all at once.

"The foreman and his two assistants ought to be well-educated artificers, and be entertained for general service, and under no restrictions whatever as to duties, as long as they were confined to the shops and their wants. Agreements for specific work, or for duties under a specific title, appear to be open to inconvenience, as has lately been experienced in the Roorkee workshops, where a man, who in his written agreement professed to serve as an 'assistant practical engineer,' (and who, from the position of Roorkee, had not only had his passage from Calcutta paid by the Government, but had received two months' salary in advance), refused on his arrival at Roorkee to do work excepting under his own 'notions,' as he called his own views, of the duties of an assistant practical engineer.

"For the establishment proposed for the timber-yard, the remark made above, on the subject of its being sufficient for present demands, and of its gradual entertainment, equally applies. The foremen I would select from their practice and knowledge of trades as useful to our object. I have no doubt that two efficient men could be easily selected for the purpose from the army. These men might remain on the town-major's list as assistant overseers; or, if procured elsewhere, might receive the salary noted on the list.

"I do not think it necessary to recommend any immediate entertainment of men specifically for the foundry department, for the reasons before specified. The establishment which we hold at present, or, rather, that which is recommended for the iron and timber yards, will give us full powers for inquiry and experiment, and will provide us with the means of proceeding on better data

than we have at present, at some future and some early opportunity."

To the above memorandum, the following abstract of the expenditure proposed to be incurred, both in increased accommodation and monthly establishments, was appended :—

	RS.	RS.
Buildings for Mathematical Department	5,000	
Do. for Foundry	10,000	
		15,000
Tools, &c., for Mathematical Department	4,000	
Dividing apparatus for Mathematical Department	11,000	
		15,000
Total original expenditure		30,000

CURRENT MONTHLY EXPENDITURE.

Supervision	Salaries	800	
	Marching allowance	100	
			900
Office	English	425	
	Native	124	
			549
Practical working establishment.	Iron yard, &c.	1,600	
	Timber yard, &c.	1,009	
			2,609
Total cost of monthly establishment			4,058

The Roorkee workshops, which, up to the 31st October, 1852, existed as a component part of the Ganges Canal works, were, from the 1st of November following, or from the commencement of an official half-year, separated from them, and placed under the superintendence of Lieutenant Allen, subject to the control of the Director of the Ganges Canal works, as an institution for the use of the North-Western Provinces, under the following orders :—

That there shall be a mathematical instrument shop and department for the supply of all instruments to the provinces north of Allahabad. That requisitions shall be made on indent, those in the survey department on the counter-signature of the surveyor-general, those in other departments on that of the secretary, Military Board.

That there shall be an iron and timber-yard for the

purpose of supplying, when such can be done economically, all articles required in the public departments. That this iron and timber yard should relieve the gun-carriage agency at Futtigurh, under emergency, in the manufacture of instruments for ordnance purposes, tools, locks, &c.; in the supply of tar, and a variety of articles at present supplied from England and from the commissariat department. It should relieve the Cossipoor foundry in the manufacture of fire-engines, forge and gun implements, weights, gauges, moulds for rockets and portfires, lathes, &c.; and it should be a nucleus for supply to the country of good serviceable articles at fair rates, on private purchase for private purposes.

That there should be a foundry for the purpose of supplying castings to the provinces north of Allahabad, and of being of general service on emergency. For this purpose the establishment above recommended was sanctioned; with a scale for the foundry as follows:—

	RS.
1 Foreman, per month	150
1 Assistant foreman, per month	100
1 Head mistrie, at 30 rs. per month	30
4 Assistant mistries, at 15 rs. per month	60
2 Carpenters, at 10 rs. per month	20
6 Labourers and stokers, at 4 rs. per month	24
Total monthly establishment for foundry	384

For the purpose of the mathematical instrument shops and foundry, with other appended buildings which the circumstances of the case appeared to render necessary, especially in warehouse room and extended accommodation for the shops in general, the following amount of expenditure was authorized:—

	RS.
Mathematical shop building	6,000
Tools for ditto	4,000
Warehouses, foundry, with contingent buildings	15,000
Total	25,000

With reference to detail on receipt and distribution,

it was determined that all instruments received from the magazines or from other departments, whether new or old, should be transmitted in the first instance direct to the superintendent of the workshops, to be by him examined, and, if necessary, repaired. The superintendent having satisfied himself that the instruments so received were in efficient order, and in a proper state for distribution, should hand them over to the principal of the college, taking his receipt for the same. The principal would then, either on the report of a committee assembled for that purpose, or (if such might be considered sufficient) on his own examination, receive them into the depôt, and from thence issue them to the different departments, on the counter-signature of the surveyor-general in the case of the survey department, on that of the Military Board otherwise. This will, of course, necessitate the building of store-rooms, which is included in the above estimate of 6,000 rupees, 1,000 rupees in addition to my original estimate having been added for that purpose.

For the increased quantity of stores, &c., which the new system would call for in the timber and iron yard, an additional 5,000 rupees, which is included in the third item of the detail of cost above given, was added to the estimate. The arrangement for the receipt and distribution of these stores was, that they should be issued (as is at present the case in the magazines) on indent countersigned by the Military Board; emergent indents being (in consequence of the distance at which the Board is situated from Roorkee) immediately attended to by the superintendent, who is to report the same without loss of time to the Military Board. With regard to the Ganges Canal works, it was ruled that they should hold a prior claim upon the Roorkee workshops, and that their demands for work or stores should supersede all others. That the officer for the time being holding executive

charge of the Northern Division, as well as the Director and Superintendent-General of Canals, should have unlimited power in procuring the aid of the workshops, and that calls from these functionaries should be attended to in preference to those from any other quarter.

The system of accounts which I recommended was *that adapted to a manufactory, as carried on by private* individuals, the plan of which was suggested and the detail drawn up by Mr. Marten, the head assistant in the office of the Director of the Ganges Canal works, whose plan of accounts for the department of public works was so highly spoken of by the committee of inquiry into that department under the presidency of Major Kennedy. This plan of account keeping will be found in the volume of tables.

The design of accounts, and the system of dealing with individuals, public or private, was to get rid of the delays which had usually accompanied the purchase and receipt of articles through the Military Board. Cash payments and settlements of accounts for articles supplied, instead of procrastinated paper records, with settlement indefinitely postponed, were the corner-stone and basis of the whole structure. It was founded on the propriety of having all accounts settled at once, and of making the shops at Roorkee a depôt, from whence all implements and stores required for the public works might be purchased by executive officers, who would buy, pay for, and charge to their account at once in the bills for works upon which they were used or expended. It would relieve the executive officer from the uncertainty which he has always been in, as to the balances against him in the ordnance books. He would proceed from year to year with a clear balance-sheet, and when his departure from office, or period for taking furlough arrived, he would at least be free from any anxiety on the subject of unexplained arrears.

On the 1st November, 1852, therefore, the workshops at Roorkee commenced a new series of independent duties, although their connexion with the Ganges Canal works then in progress, and their occupation on wood and iron work solely for canal purposes, would for some years curtail their general usefulness. The enormous demand for bricks not only for the Solani Aqueduct, and the work directly appertaining to the Ganges Canal, but for the college buildings and numerous bungalows under construction for students, rendered it quite impracticable at that period to make any active movement in the building which was called for by the newly-organized institution. At that time, therefore, the shops were necessarily limited to their engagements, and to the accommodation that they previously had. The designs for the new buildings, however, were placed in the hands of the executive engineer, so that when opportunity offered he might carry them on, if only by slow and gradual means. This has, in fact, been done. The basement stories of the northern face, a well, and certain other buildings attached to the foundry and mathematical department, have been in slow progress. The clearing off of the Solani Aqueduct works, and the completion of the college buildings, both of which unfortunately had to be simultaneously carried on, will lead to the rapid finishing of all the buildings and improvements required for the shops.

In the meantime the arrangements for the receipt of instruments from the magazines, and the establishment of the depôt at the college, have been necessarily placed in abeyance. In fact, at the period that I am writing, although a good deal of the initiative proceedings have been gone through, and the groundwork has been laid for ultimate progress, these workshops are essentially in their infancy, and may be considered as by no means

introduced to the public as an establishment for general utility.

Before closing the account of the workshops in their new position, I may remark on the arrangements for money advances, and the possession of capital, as we may term it in this case, which the superintendent of the shops holds for carrying on business.

As on the separation of the shops from the Ganges Canal works, nearly the whole of the work done by the shops was for the canal. The executive engineer of the northern division of the works was directed to make advances of even sums of 10,000 rupees, these sums being, in fact, advances on a running account that must necessarily exist between the canal and the workshops. The same system would be adopted where any public establishment drew largely or regularly on the Roorkee workshops for supplies. Advances, for instance, must be made to the shops for the manufacture of fire-engines, lathes, and tools, for which orders are received from the Military Board. In the latter case, and in all others where articles are manufactured for the general purposes of the State, these advances would be made by assignments given by the Accountant-General North-Western Provinces, in the same form as assignments are now given to the canal department for current expenses, viz., by application by the superintendent of the workshops to the director of the Ganges Canal works, who would hold in his hands the power of acting on an annual assignment granted by the Government on an annual estimate submitted by the superintendent of the workshops through the director. The amount of this annual estimate in the early period of the shops' operations must necessarily have been uncertain. It was clear that, if advances were received in the workshop treasury from public departments for everything manufactured for their

use, or if everything manufactured for general use was sold to the public, the *only assignments* that the Government would be called upon to give would be a certain capital in the first instance to carry on the manufacture of articles and for monthly establishment. The first of these would be gradually decreased in amount as the sales of articles took place, and the latter would in all probability cease, from the factory being able to pay its establishment from its own receipts. At the commencement, and during the early period of progress, the following arrangements were determined on :—

1st. All *purchases of stores, such as iron, timber,* &c., should be made on estimated advances, for which an application for an assignment would be submitted by the superintendent on the 1st of May annually.

2nd. That all purchases of machinery or implements required for the different departments of the workshops should be procured in a similar way; in the way, in fact, which is now done elsewhere, viz., by submitting an application to Government for permission to purchase, and by obtaining an assignment for the purpose.

3rd. That until we hold better *data* than we have at present, the average cost of labour and sundries for the last twelve months, including the increased salary to superintendent, &c., should be taken as the probable monthly expenditure on these items, and that power should be given to the director to grant periodical assignments in sums the total of which should not exceed that monthly average.

	RS.	A.	P.
Average expense per month on labour and sundries	6,500	0	0
Average expense per month on regular establishment	1,500	0	0
Total per month	8,000	0	0
Total per year	96,000	0	0

The total per year, as above noted, being the amount of expenditure for which an annual assignment will be granted.

On the above rules, and with the authorized sum as above noted, the Roorkee workshops have been carried on up to the present period. The arrival of a successor to the practical engineer who accompanied me from England, and who returned at the expiration of his service, as well as that of a very superior workman in the mathematical instrument department, have placed us on an excellent footing in preparation for more extended proceedings on the completion of the new accommodation. The former, Mr. Watson, gives promise of being a great acquisition in all departments. He has established the certainty of success in iron-casting, and has with a small cupola temporarily erected, done a good deal of work which must otherwise have been made at a distance. The latter, Mr. Crible, was for a long time in the surveyor-general's office in Calcutta, employed on the repair of both surveying and mathematical instruments. Even with the want of room and conveniences which he has experienced since his arrival at Roorkee he has turned out small surveying circles, or circumferentors, for the use of the natives, and other descriptions of common instruments, that would do credit to the professional artist of London. I believe that these shops only require to be completed, with proper accommodation for the different departments to which they are destined, to do full justice to the intentions of the Government.

Early in 1853, the following machinery, in addition to that which was formerly received, was ordered from England:—

A 20-horse-power, high-pressure, beam steam-engine.
A slotting and paring machine.

A small drilling and boring machine.
A small planing machine.
A plate-bending machine.
A large self-acting lathe.

The engine will be attached to the foundry-yard, and in connexion with the mathematical department. It is by no means improbable that it will be found convenient in economizing space to remove the northern wall of the old quadrangle or iron-yard, and by so doing, to throw the foundry and the quadrangle area into one enclosure.

My original idea of having quays and fixed cranes on the side of the canal in connexion with the workshops will also be greatly improved by a proposal of Lieutenant Allen's, viz., the construction of a dock in the centre of the timber-yard, connected with the canal by an open channel bridged over the canal bank and berms. It will enable goods to be floated *into* the yard, and give us the means of loading and unloading within the precincts of the workshops, and in the immediate neighbourhood of the warehouses. It will also give great advantages to our boat-building operations in floating the boats away as soon as they are built. Practically speaking, the construction of this work will be an economical one, as it will, in the excavation for the dock and canal of approach to it, give earth for raising and levelling ground in the yards, which, in spite of the quantity of work of this description that was done in the early stage of our proceedings, is very much wanted. The only inconvenience that I see to this side channel, which will leave the canal at the commencement of the ogee on the approach to the bridge, is, that its mouth will be a harbour for silt deposits, and that, by opening a passage through the workshop wall for the canal, ingress will be obtained by those who have no business there. In the former case the silt clearance would be effected

at periods when the canal was laid dry, and the silt itself, if not required elsewhere, would be thrown into the main canal bed on the down-stream side of the dock channel-head, as it could not be allowed to encumber the esplanades or roadways. In the latter, provision might easily be made in the shape of a portcullis or some protective expedient by which ingress into the yard by that passage would be prevented.

By referring to the map of Roorkee it will be seen that I have reserved spare ground to the south of the timber-yard, and have not allowed it to be occupied by either private or public buildings. The road which has been carried across it has been allowed merely as a temporary convenience. My object has been to retain the whole of the land in the neighbourhood of, and parallel to the canal, for purposes of the workshop, so that the enclosure or buildings required for its use may be collected in one compact mass. That portion of this ground lying in close proximity to the private estates on the east, and which lies out of the alignement of the east wall of the quadrangles, has been proposed to be occupied by the quarters of the European establishment attached to the yard; the flat-roofed buildings on the north-east angle of the foundry being considered as more applicable for providing additional accommodation to the shops than to that of private residences. Thatched roofs and a free circulation of air are certainly more adapted to salubrity than a series of connected rooms attached to the body of the workshop buildings. The ground at the present time is occupied by timber; it is separated from the timber-yard enclosure by the high road and ramp of approach to the bridge, an impediment which can be easily overcome by a passage of communication built under the road. This, with the

free use of rails, a quantity of which will, on the completion of the canal works, be disposable, will connect the whole of this extended line of shops and yards in one convenient series.

At present, the model department and libraries, both professional and non-professional, are under the executive engineer of the northern division of the Ganges Canal works, although the rooms form a part of the workshop buildings. These are specifically for the canal department, and for study and reference for the students of the Civil Engineers' College. A librarian, for whom a salary of 40 rupees a month is allowed by the Government, has not yet been entertained. The present state of the libraries, and the small number of books contained in them, hardly called for a substantive appointment of this sort, the duties having been performed by the head writer in the executive engineer's office on a reduced allowance. A list of the books will be found in the volume of tables.

The model room is at present by no means fully occupied, and its contributions are chiefly models of works which have been built on the canals in these provinces. Its nucleus may be dated as far back as 1831, in the model room of the Eastern Jumna Canal, which progressed under my successors, and ultimately was removed in mass to Roorkee. It possesses, nevertheless, some interesting models besides those of canal works, and as a beginning to a more perfect series is satisfactory.

The clock tower, the basement story of which acts as the vestibule from the open esplanade which lies to the east of the buildings, is built on a design by Lieutenant George Price, deputy superintendent in the canal department, the architect and designer of both the church

(vignette, vol. ii. p. 60) and the college (title-page, vol. iii.) It is a neat plain building, campanile fashion (vignette, vol. ii. p. 381), in so far that, although in contact with the mass, it is built separate from the main building, of which it forms a part. The clock is an eight-day one made by MacCabe, with four faces, and with a strike that is heard very distinctly over the whole extent of the works.

In conclusion, I may observe, that nominations of officers to the workshops have been confined to those only who have appeared to possess peculiar claims for the office. Vacancies still exist, which may be filled up as opportunities offer; but at an out-of-the-way place like Roorkee, removed altogether from contact with Calcutta, or any of the large towns of India, we are, in a measure, cut off from connection with men who are fitted to the work. A greater disadvantage, perhaps, is the absolute necessity for procuring men at a great expense from distant points, on certificates of character and professional knowledge which experience may point out to be altogether fictitious. This is an evil to which we are open at present, although railroads, and by their means the introduction of practical engineers into the country, may place us on a different footing hereafter. In Lieutenant Allen as the chief, we have in all departments of machinery an excellent superintendent. In Mr. Watson as a practical engineer, we have a young rising man with a great deal of professional knowledge, backed by other acquirements which render him worthy in every way of maintaining a high position in the workshops. In Mr. Crible, the mathematical instrument maker, we have an equally efficient member of our young establishment. We require more aid, however; and I consider that this can only be satisfactorily gained, by a deliberate selection of men. The following table exhibits

the present state of our European superintendence in the workshops, with the vacancies still existing:—

Lieut. Allen, Superintendent.
" Read, Acting Deputy Superintendent.
Mr. J. L. Watson, Practical Engineer.
" W. J. Crible, Assistant Mathematical Instrument Maker.
" Corrigan, Bookkeeper.
" Pigott, Assistant-Bookkeeper.
" Pocock, Clerk.
Sergt. Neilson, Assistant-Foreman, Iron Department.
" McArthur, Storekeeper.
Corporal Aitchison, Moulder.

VACANCIES.

1 General Musterer.
1 Assistant-Foreman, Timber Yard.
1 " " Foundry.
1 Clerk.

Lieutenant Read, of the 50th Regiment N. I., a deputy superintendent in the canal department, is at the present time acting as an assistant to Lieutenant Allen.

It does not appear worth while to pay any specific attention to the temporary workshops that have during the progress of the works been attached to each of the divisions; both they and the divisions themselves hold tenure merely on the progress of the works, and will be broken up and discontinued on the new organization of the establishment depending on irrigation. Their occupation has been chiefly confined to the common routine duties of each division, making doors for the choki buildings, woodwork for the sluices and regulating heads, and all woodwork required for divisional purposes.

Section II.—Mills.

The only arrangements which have been made for machinery of this description are for grinding corn, and the machinery itself is the common punchukki, or native corn mill of these provinces. Buildings for this purpose

have either been constructed, or are about to be constructed at the following places :—

Kunkhul, Bahadoorabad, Assoffnuggur, Muhmoodpoor,	Saharunpoor District.
Belra, Jaoli, Chitowra,	Muzuffurnuggur District.
Sulawur, Bhola, Dasna,	Meerut District.
Pulra, Simra,	Alligurh District.
Cawnpoor Terminus,	Cawnpoor District.
Etawah Do.	Do.

The merit of the punchukki is, its exceeding simplicity, its perfect adaptation to the natives who are called upon to use it, its excessive cheapness, and the ease with which it is replaced or repaired. Its defects are loss of power, in requirements for a larger body of water than would be necessary with the turbine. These defects, however, are in our case negatived by the mills being placed in such a position that the water in its progress down the canal passes through the shoots of the mills, and rejoins the parent stream through their waste channels. With the quantity of fall, therefore, that we have, and with water sufficient for the purposes of the punchukki, much as I esteem European ingenuity and invention, I have preferred supplying the native of India with his own simple mill, the use of which he perfectly comprehends, and the repair of which he can effect either by his own means, or by those of the nearest village carpenter. Turbines, &c., may come hereafter, and will, I have no doubt, do so with great advantage to the rising generation.

The only deviation from the above rule of the water proceeding through the mill shoots and rejoining the canal

through the waste channel of the mills themselves, is in the establishment at Kunkhul. These buildings have not yet been constructed, but should they be so, their situation on the edge of the branch of the Ganges, just *below the town of* Kunkhul, will militate against the above economical principle. In this case, the water, after passing through the mills, will run into the branch, and, although not actually to waste, as providing the means of irrigation to a quantity of low ground that lies in the neighbourhood, the principle is opposed to the practice which I desire to see accomplished. My only object, in fact, in estimating for mills at Kunkhul, was to give a ready supply of flour to the inhabitants, and I did this even to the neglect of a principle, in consequence of the main stream of the Ganges being in such close proximity that additional water might be admitted into the canal channel to meet the demand of the mills.

The design for the *Kunkhul Mills* is shown in Sheet 17, Atlas. It is similar to that figured in the estimate of 1845. It consists of an octagonal basin, with its lateral faces occupied by mill buildings, the two remaining sides acting as the ingress and egress channels. The design gives space for sixteen pairs of stones, which will grind in the aggregate from 800 to 1,000 maunds of corn a day. Supplemental to this nest of mills, more especially for the use of Kunkhul, the town of Hurdwar will be supplied by detached mills, which may be built either by the Government or by private contract, on the branch lying between the main stream of the Ganges and the regulating bridge and dam at Myapoor.

The *Bahadoorabad Mills* are built upon the site of No. 1 lock, as designed in the project of 1845. They are situated between Jowallapoor and the village of Bahadoorabad, at a distance of a mile from the latter. Here there are arrangements for sixteen pairs of stones.

The mills lie on the right and left of the navigable canal into which the waste water passes. The head of these mills is situated on the high levels above the Ranipoor super-passage, and the reservoirs connected with them are supplied with outlets from which water for irrigation can be delivered to the neighbouring village lands. These works are in progress of construction.

The mills at the places noted in the above list from Assoffnuggur to Simra, are connected with the waste chambers of the locks at the different falls. They are built on one design; and in construction, the revetment wall connected with the canal face is so laid out, that additional mill buildings can be added afterwards, should an increase to the number of stones be desirable. At each of the locks above alluded to, there are two mill houses, each of which contains two pairs of stones. The supply for the wheels is received from the higher levels of the lock, and the water passes off into the lock waste chamber.

The terminal works on the Cawnpoor and Etawah lines are constructed on a similar principle to the above. The buildings are detached from the locks and line of canal, from which they are separated by the esplanade or open road which flanks the canal channel. They receive their supply, from the high levels, and pass off their waste water on the lower ones. A plan of one punchukki, however, is that of all. They differ in nothing excepting in length of shoot depending on the amount of fall of water passing upon the wheel, and in the arrangements necessary for the discharge of waste water.

I may conclude this chapter with a short account of the native water-mill, which was published by me in the year 1833 in the Journal of the Asiatic Society, as, without any disrespect to turbines and other ingenious

devices, I have always considered, and do still consider, the punchukki of the North-Western Provinces of India, a machine possessing extraordinary claims for adoption amongst a class of people like those with whom we have to deal in the canal department.

"On the mountain streams and rivers in the northern Doab, the natives use a water-mill for grinding corn, which, from its simplicity, is well deserving attention. It might be applied in all countries where a sufficient fall and quantity of water can be commanded. Where a want of efficient workmen renders the repair of complicated machinery difficult, the punchukki would be of great service. In the hands of the natives, and with the rude means at their disposal, it may be perhaps considered the only sort of mill that could be turned by them to any account. From the simplicity of its construction, it can, at a trifling outlay, be fixed or removed at pleasure. The only weighty parts about the punchukki, in fact, are the mill-stones, which (by running a stick through them, and yoking to it a bullock or pair of bullocks) may be removed with as little difficulty or expense as the rest of the machinery..

"A horizontal water-wheel, with floats placed obliquely so as to receive a stream of water from a shoot or funnel, the said floats being fixed in a vertical axle passing through the lower mill-stone, and held to the upper one by a short iron bar at right angles, causes it to revolve with the water-wheel. The axle itself works on a piece of the hardest stone that can be procured from the shingle near at hand. A thatched roof covers the whole; this, with the expense and trouble of digging a cut so as to take advantage of a fall of water, is the only requirements for this very simple mill. The plan is obviously good, not only for the means gained, but for its possessing a simplicity which renders it almost

independent of repair. It is, moreover, intelligible in its parts, and comes within the comprehension of the simplest understanding. The punchukki has been adopted generally in all the canals in the Delhi district, as well as in those of the Doab, and with such success, that its introduction is as much an object on account of the profit arising to the canal returns, as from the accommodation and convenience offered to the community, in providing the means for grinding corn.

"On reference to the accompanying plate,* it will be seen that the motion is direct, and that the adjustment of the machinery depends entirely on the lower pivot. It will also be seen that there is not a part of the whole machinery that could not be repaired and put in perfect order by the commonest village workman—a matter of importance in the absence of mechanical skill and practised artificers. Whereas, in the plainest undershot wheel applied to a mill for grinding corn, there are no less than three wheels of different descriptions—the change of vertical to horizontal motion—and three pivots; with friction, even under the most skilful management, tending constantly to disarrange the parts, and render the presence of a forge and blacksmith's shop indispensable.

"On the canals it has been found worth while to construct permanent buildings for these corn-mills; and although keeping most strictly to the original simplicity of the machinery, they are set up with greater care, and means are given for regulating the motion, &c., which renders the whole as perfect as it can well be.

"It would appear that a fall of water (that is to say, the difference of level between the surface of the head supply and the float boards of the water-wheel) equal to 3 feet, is the minimum in which this species of machinery can be used with any good effect; and it has been found

* Vide p. 382.

that, with a fall of three feet, the dimensions of the shoot or funnel require an addition in width to obtain that by weight of water, which the smallness of the fall will not give by velocity alone.

"The following are the particulars of mills on the Eastern Jumna Canal, divided into three classes depending on the depth of the fall; the width of shoot on the sill or waste-board being 12 inches, and the discharge per second averaging 1·5 cubic feet; the diameter of mill-stones 27 inches, and thickness 12 inches; the corn being ground into atta or coarse flour:—

Class.	Fall of Water.		Atta ground per hour.		
	Feet	In.	Mds	Seers.	
No. 1	7	6	1	26	or 132 lbs.
" 2	5	5	1	5	or 90 "
" 3	3	6	0	17	or 32 "

"The common mills used in the Jumna and mountain streams are said to grind from 5 to 7 maunds of atta per day, or in 24 hours; the machinery being of the rudest description, the supply of water being very small, and a great part of that escaping through the shoot before it touches the water-wheel.

"The return to Government on the mills is obtained generally by farming them out to contractors for fixed periods, who pay so much per day as long as a supply of water equal to that entered in the contract is provided, regulated by the depth of water on the sill or waste-board. This return, of course, varies not only with the power of the mills, but also with their position relatively to populous towns and cantonments. In the neighbourhood of Delhi the demand for atta is great, and the consequent return equally so; whereas, at other points distant from towns, mills of equal power do not produce half the return. The Eastern Jumna Canal, although

possessing every advantage in fall and power of machinery, labours under a disadvantage in this respect, the town of Saharunpoor being the only one throughout its whole extent where there is any great demand for machinery of this description. Shamli, although a large town, does not contain a great number of that class of people who purchase atta, each family grinding their own corn for home consumption; and, although there are ample means for establishing mills at the south end of the canal opposite Delhi, (the canal falling into the Jumna with a descent of about 50 feet in a line of 12 miles!) it has been considered unadvisable to put them in extended practice, on the supposition that the mills already built on the Delhi Canal in the city would suffer from the competition; in short, that the mills in Delhi are sufficient to grind the corn required by its population.

"The people from whom the millers look for profit are chiefly those of the sipahi class, travellers, those without families, idlers, &c. Those who are regularly settled with their families, trusting to the hand-mill in their own house, and not purchasing from the mills, excepting on marriages and other grand occasions, when the consumption of atta is more than their own mill could provide for. In military cantonments the whole of the atta and flour used is obtained from the mills; the vicinity, therefore, of a station of this description becomes a lucrative affair to the miller, in exemplification of which I may mention that during the existence of the provincial battalion at Saharunpoor, the canal mills at that place were kept constantly in their service, with little or no aid from the inhabitants of the town.

"The profit derived by the renter of a mill depends in a great measure on his management, and on the rate per maund which he charges for grinding; but with an experienced and steady man, the following may be considered

as a very close approximation to the daily profit. The rate per maund for grinding atta by the peesunyaris or corn-grinders in the city is generally three annas, for which sum they deliver the article at the purchaser's house. At the water-mills two annas per maund is the usual charge, not, however, including the carriage of the grain to the mills, &c., the charge of two annas being simply for grinding.

"The expenses to the miller for keeping two mills at work are thus:—

		RS.	A.	P.
Per Month.—	1 Head Miller's wages	5	0	0
"	1 Assistant Miller's wages	4	0	0
"	1 Weighman	4	0	0
"	Oil at $\frac{1}{2}$ a seer per day . . about	1	0	0
"	2 seers of atta given per day to 2 millers in addition to their regular pay, about	2	7	0
	Total expense per month	16	7	0
	Or, per day, taking a month of 30 days	0	8	$9\frac{1}{5}$

The receipts per day are as follow:—

Supposing 55 maunds of grain ground, at 2 annas per maund				6	14	0
Deduct:—						
Expenses as above	0	8	$9\frac{1}{5}$			
Government rent	5	0	0			
				5	8	$9\frac{1}{5}$
Balance, profit to miller per day				1	5	$2\frac{4}{5}$

"An additional or third mill would increase the profits to the contractor without a proportionate increase to the expenditure; whereas, a solitary mill would require the same establishment as that noted in the above table. Mills of a higher power also might be easily worked on the above scale.

"At mills distant from towns the payment for grinding corn is made in kind, varying from two to four seers per maund, which, at the usual rate of from forty to fifty

seers per rupee, is but a moderate return in comparison with that of the town mills. These village mills grind grain, barley, and Indian corn, as well as wheat.

"The stones used on the canals are chiefly those from the quarries near Agra, Roopbas, and Futtipoor Sikri,—a coarse-grained sandstone, which requires the chisel every second day. There are three sizes used:—

1st size,	diameter	36 inches,		depth 12 inches.	
2nd ,,	,,	30	,,	,,	
3rd ,,	,,	27	,,	,,	

The two latter are in most general use. Stones of the usual quality last for about two or three years; that is to say, at the end of that period a new upper stone is provided, and the old one is placed below. In the native mills on the Jumna, stones about 22 inches diameter, and from 10 to 12 inches thick, are quarried in the vicinity of Rajpoor, north of Deyra. They appear to me of an inferior description, though of various qualities; the native millers, however, prefer some of them to the Agra stone; and it is not impossible that some of the best variety from Rajpoor may be superior to the worst from Agra, but generally speaking the preference is decidedly in favour of the latter.

"The best method of delivering the water from the shoot on to the float boards, appears to be that represented in the accompanying sketch,* and which has been generally practised on the canals, in pursuance of the usual course adopted by the natives. A trial made at Hansi, in which a horizontal (or nearly horizontal) shoot, applied to the lower part of a cistern, delivered the stream on float-boards, whose planes were parallel to the axis of the arbor or upright, did not answer so well as was expected. The introduction of a new system, unless palpably advantageous, is certain to meet with

* Vide p. 382.

objections from the people to whom the mills are intrusted. I am much inclined, however, to consider that the horizontal method of applying water to this simple *water-wheel is inferior to that adopted* by the natives—a matter to be settled by practical experiment, and not by theoretical speculations. Belidor, in speaking of a mill of this description, says:—

"'En Provence et dans une bonne partie du Dauphiné, les moulins y sont d'une grande simplicité, n'ayant qu'une roue horizontale, de 6 ou 7 pieds de diamètre, dont les aubes sont faites en cuillères* pour recevoir le choc de l'eau, qui coule ordinairement dans un auge; l'arbre, qui répond à la meule supérieure, est la seule pièce qui sert à lui communiquer le mouvement, et je ne crois pas qu'il soit possible de faire un moulin à moindre frais; il est vrai qu'il faut pouvoir ménager une chute comme celle que l'on voit ici, et qui sont très frequentes dans ce pays là.

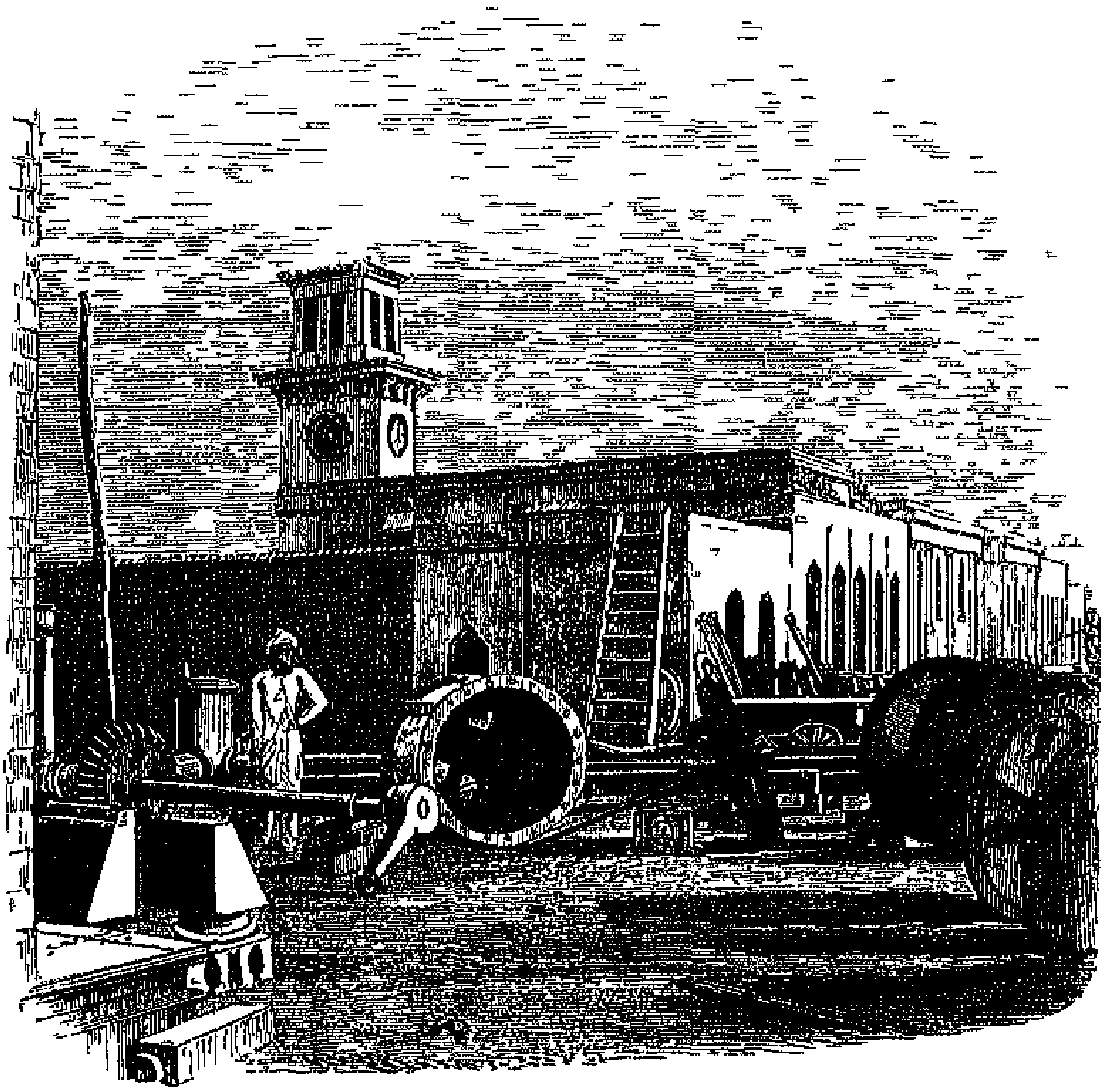
"'La roue tourne sur un pivot dans une crapaudine pratiquée au milieu de l'entretoise du chassis, servant à approcher les deux meules, par le moyen de la vis ce qui est à l'extrémité de la pièce, et de l'écrou, quo l'on fait tourner pour hausser ou baisser le chassis.

"'Les roues que l'on voit exécutées dans le goût de celle-ci ont leur cuilleres simplement assemblées à l'arbre par un tenon et une cheville, fortifiées par le-dessous par des membrures qui les entretiennent toutes ensembles.'

"He goes on to explain a method of opening and shutting the water-course or shoot, which is of no consequence here. It will be seen, however, that the

* These cuillères, or spoon-shaped ends, are mere indentations in the native mills, and the trough alluded to by Belidor for the delivery of the water at an angle of about 25 deg., is in the native mills a square tube or shoot placed at an angle of 45 deg. The crapaudine and the arrangement for raising or depressing the upper stone by the transom in which it is fixed, is also practised in the native mill.

Provence mill is exactly on the same plan as that used in this part of India, and it is a pity that the account did not proceed and explain the powers of the mill, that we might draw a comparison between the two. It would also be interesting to know whether the increased size (the Provence mill being about double the size in diameter of water-wheel, &c.) would not detract from the simplicity of the little native mill. The great advantage of the latter appears to be the absence of complicated wood and iron work, especially joints and iron bindings, &c., all of which increase with length of lever, or length of radii of the water-wheel: indeed, the above account shows a complication of membrures, &c., which in the native mill is not thought of."



VIEW FROM INTERIOR OF ROORKEE WORKSHOPS, SHOWING CLOCK-TOWER

REFERENCES TO PLATE

Fig. 1.—Elevation of the water-wheel, with the stones in section, to represent the iron spindle.

At *x*, a hole of about 4 inches diameter, and 4 inches deep, is made in the transom, into which a quartz boulder is firmly fixed; the said stone or boulder having an indentation made into it to receive the pivot.

This pivot, as represented in Fig. 4, consists of another stone of the same quality, of about 4 or 5 inches long, and 1 inch square, which is firmly fixed into the tail of the arbor (see *y*). The above stones are picked up in the beds of the mountain rivers, and are used as they are found, without any stone cutting.

Fig. 2.—Plan of waterwheel, 30 float boards of Sissoo wood.

Fig. 3.—Upper joint of arbor.

Fig. 4.—Lower joint of arbor, showing the iron straps fixed between each float-board, to keep them firmly in position; the strap represented in Fig. 5.

Fig. 5.—Strap as above.

Figs. 6 & 7.—Float-board, and end of ditto; the float-board 12 inches long, with a spoon sunk 4 inches in length.

Fig. 8.—Iron ring that slips over the top of arbor, and holds the two joints together.

Figs. 9 & 10.—The spindle and plate upon which the upper mill-stone turns.

Fig. 11.—Sketch of mill-stones, with basket, stand, &c.

a.—Hopper or basket.

b.—Shoe.

c.—Feeder, or small piece of wood hanging to one lip of the shoe, and resting on the mill-stone, each revolution of which gives the shoe a jog, causing the corn to run constantly from the hopper through the shoe.

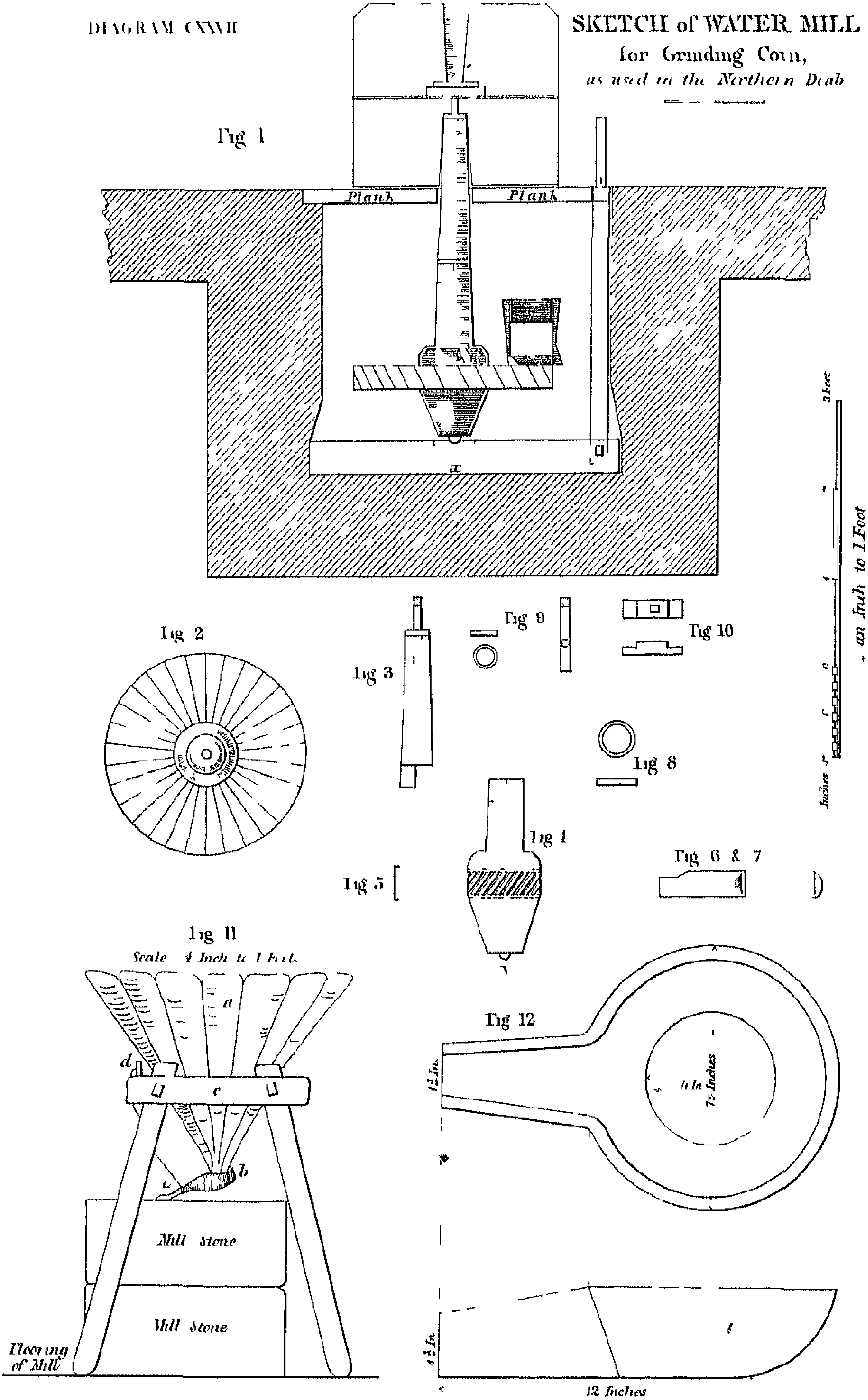
d.—String attached to the opposite lip of the shoe, to which the feeder is, and by tightening or loosening which, the discharge of corn is regulated.

e.—Stand.

Fig. 12—Shoe on a large scale; this is generally cut out of a block of dak (*Butea frondosa*) or any wood easily worked.

DIAGRAM CXXVII

SKETCH of WATER MILL
for Grinding Corn,
as used in the Northern Doab



CHAPTER VIII.

TERMINAL WORKS.

THIS chapter may be divided into the following:—

Section I.—Works at the Cawnpoor Terminus.
II.—Works at the Etawah Terminus.
III.—Works at the Termini of the Branches.
A. Futtigurh Branch.
B. Bolundshuhur Branch.
C. Koel Branch.

I. *Works at the Cawnpoor Terminus.*

The works connected with this section commence at a point 5 miles 750 feet from the Ganges River, near the village of Dubowli; the leading one being an escape for the purpose of regulating the water on its approach to the town and cantonments of Cawnpoor, through which the canal is carried on its descent to the river. The Dubowli Escape is, in fact, the work by which the canal supply is regulated on the various locks, mills, &c., of which the terminal works are composed; and it naturally takes the precedence, both from its position and from the services which it is called upon to perform.

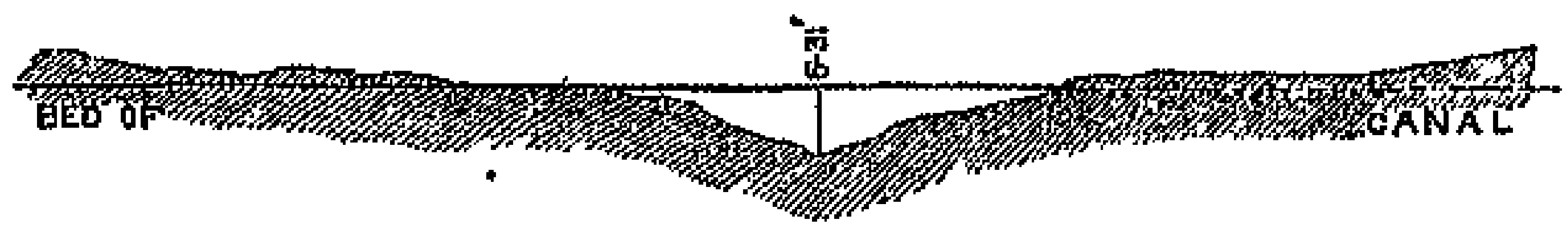
The Dubowli Escape (plan and section of which are given in Plate XLII. of the Atlas) is situated at a point 11,187 feet below the Kujoori Bridge, or that by which the high road between Cawnpoor and Kalpi crosses the

canal. It is built across a tributary of the Pandoo River, which lies 8,000 feet on the right, and it combines with its services as an escape for canal water, a passage for the drainage of the tributary across which it is carried.

The canal channel at this point is an aqueduct. The drainage which is collected from a hollow of about one square mile in extent, immediately on the left of the canal embankments, passes by arched channels underneath the canal.

The section of the valley or hollow over which the aqueduct passes is shown in the following diagram, the horizontal line representing the level on which the bed of the canal runs, with reference to that of the nulla:—

Diagram 128.



From its intersection by the aqueduct to the Pandoo River, the nulla has a slope of 15·6 feet on a total length of 10,000 feet. Its course is tortuous, with a deep and narrow section, which, on its junction with the Pandoo, assumes the character of a ravine. The great depression of the bed of the Pandoo, below that of the flooring of the sub-channels at the escape, renders the back water arising from high floods quite harmless in its effects upon the canal works.

The rain-water collected at the head of this line of drainage is inconsiderable, the catchment basin lying above the canal not exceeding, as I have before remarked, one square mile in superficial extent.

For the passage of the drainage water collected in the basin, three bays of 6 feet each in width, and with a height of 4 feet from the flooring to the soffit of the arch, have been given on the up-stream side; the floor-

ings themselves being built with a rapid slope, so that the discharge outlets in the down-stream direction have a height of 6 feet. This slope of 2 feet is on a length of 107 feet, or on the whole width of the building.

An inspection of the plan will convey a much better idea of the design of this work than I can give in a written description; it will be sufficient, therefore, to observe that the channels above described become the receptacles of the escape water from the canal on the upper levels, through a series of side openings—three of which are situated on each side of the canal; the total width of escape waterway thus provided being equal to 36 feet. These side openings of 6 feet each in width, discharge their water down perpendicular drops which open into the lower channels, the fall and momentum of the fluid being broken by bars of stone placed across the upper part of the drop, and by wells or reservoirs below, which receive in the first instance the body of water, and ease off its action before it proceeds onwards down the bed of the nulla.

The slope which has been given to the waste channel floorings, and the increased capacity which has been obtained to the nulla itself, by widening it out from the down-stream side of the building, as far as the junction of the nulla with the Pandoo, render the escape both for country and canal drainage purposes very efficient.

The external faces of this building are flanked by semicircular revetments, which on the left bank are surmounted by houses for store and choki purposes.

The canal channel, which is 20 feet in width, has on each side a berm of 10 feet, with a roadway of 20 feet in width, the whole forming a compact body of work; with steps of approach to the water in the canal channel.

I may here observe that the berms, or towing-paths,

which on the whole line of the canal had been raised 8 feet above the bed of the canal, are from the Kujoori Bridge to the Dubowli outlet gradually diminished, until at the latter work they stand 6 feet above the canal bed; *at this height they continue throughout the whole of the terminal works* which I am now describing. The canal channel on its approach to, and departure from the masonry work of this building, is carried over well-made and carefully consolidated embankments, to which the semicircular form of wing revetments is well adapted.

These works are built entirely of brick masonry, with the cement made of the following proportions:—

Four-fifths kunkur lime.
One-fifth soorkee.

The quantity of cubic feet of masonry is 48,426.

The rates per 100 cubic feet were Co.'s rupees 16-6-3, and the total cost amounted to Co.'s rupees 9,241-13-9.

The Dubowli Escape was built by Lieutenant Hodgson, of the Engineers.

At a distance of 1,207 feet below the escape is the Dubowli Bridge. On the up-stream side of this work *the rajbuha head leading to the line of irrigation running* between the Pandoo and the Ganges is situated. (See plan, Plate XLIII.)

The bridge itself is for village purposes, but the works attached to it are designed for escape as well as *for irrigation.* Here we have *a drop gate, which, being* placed immediately below the rajbuha head, and across the canal channel, acts both for the purposes of regulating the supply of water for irrigation, and for preventing the onward passage of water towards the Cawnpoor works. In the latter case, the six openings at the Dubowli Escape, as well as that for the rajbuha, become the outlets for the waste water; the rajbuha playing its

part for any water that may fail in escaping through the six openings at the Dubowli Escape.

The rajbuha head at this bridge is the last opening for irrigation on the Cawnpoor Terminal line, its width is 10 feet, and its sill or flooring is on a level with the canal bed; the opening, in fact, is so devised that in case of necessity all spare water may pass down the rajbuha channel, whilst the main line on the down-stream side of the shutter is laid perfectly dry.

The design of this bridge is plain: a 20 feet segment of 60 deg. for the canal channel, with side towing-path passages of 4 feet in width, flanked by rusticated pilasters. The width of roadway is 18 feet, and steps of communication between the high and low levels are attached to both the up- and down- stream wings. The front of the rajbuha head, as well as the opposite side of the channel, is covered as usual with flights of steps, and the full width of the berm is secured by a retaining wall on the same plan as has been designed at the other bridges. The masonry channel on the up-stream side of the bridge is laid out with reference to the best plan for directing the current upon the line of rajbuha.

This work is built of brick masonry, with cement of the following ingredients:—

Four-fifths kunkur lime.
One-fifth soorkee.

The cubic content is as follows: 25,184 cubic feet. The rate per 100 cubic feet of masonry was Co.'s rupees 17-6-5, exclusive of plaster; and the total cost of the work was Co.'s rupees 5,010-1-7.

The work was built by Lieut. Hodgson, the Executive Engineer of the Cawnpoor Terminal line.

The Ducknapoor Bridge, or that for the passage of the Grand Trunk Road between Allahabad and Alligurh, is situated 14,176 feet below the Dubowli Bridge above

described; it is similar also in design, with exception to the width of towing-path passage being 5 feet instead of 4 feet, and in the latter having segmental instead of circular arches.

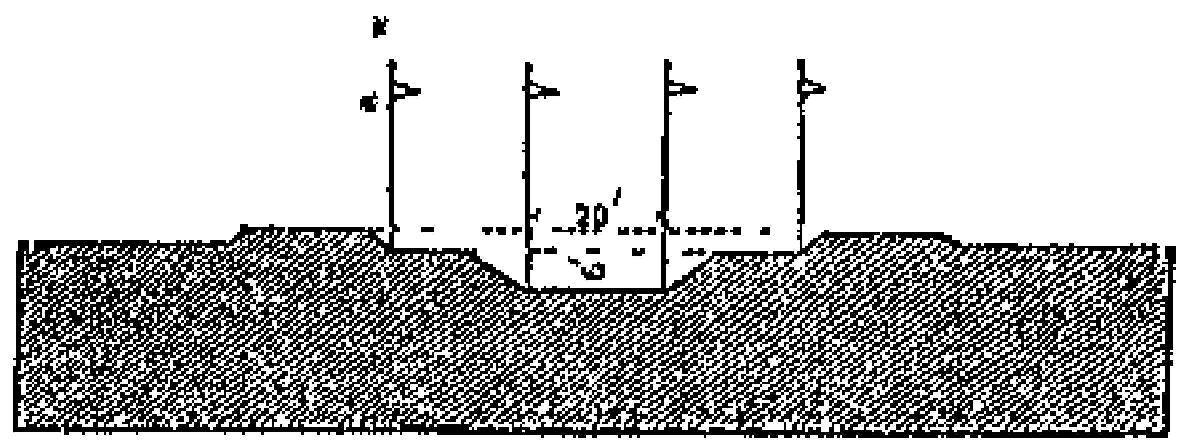
This bridge is built on a skew at an angle of 65 deg. corresponding exactly with that on which the road and canal intersect each other. The width of roadway is 25 feet, and the up- and down- stream faces in connection with the canal channel are flanked by semicircular revetments adapted to the towing-paths.

On the whole of the line of canal upon which the works above described are situated, the course has been on a gradual curve, directed upon the boundary separating the city of Cawnpoor from the military bazaar of the cantonment. The depth of excavation varied from 8 to 16 feet, and the soil is good, especially on the surface. In the immediate neighbourhood of the Duknapoor Bridge and the Grand Trunk Road the existence for a long period of brick-kilns is a proof that the supersoil at least is formed of good brick earth.

After leaving the Duknapoor Bridge the canal runs for a length of 3,744 feet, still on a curve, through a good deal of broken ground arising from the brick-kilns above mentioned, until it reaches the angle of the city, at which the leading bridge, or No. 1, connected with the series of works which continue to the Ganges River, is situated. On the up-stream side of this bridge, the channel passed through an extensive hollow caused by the excavation of earth for brickmaking; here there was a necessity for a good deal of artificial embankment, but the soil is good, and the brick-kilns, or native puzawas, which lie on the right and left of the line, provided an ample supply of material for all purposes. The berms, as I have before mentioned, are continued at 6 feet in height from the canal bed, and the section of the canal

from the Dubowli Escape to the point at which we have now arrived may be understood from the following diagram:—

Diagram 129.



The canal from the head of the terminal works at the Dubowli Escape to this point, passes through an excavated channel, on a gradual curve, the total length being 19,127 feet. Forwards, and in advance to the Ganges, the length being 7,973 feet, the sides are revetted with masonry, and fitted with the necessary accommodations for giving access to the water to the inhabitants of a populous town. Up to No. 1 Bridge, the line, having been carried through open country, was attended merely by the remission of revenue for land appropriated. In advance, house and garden property had to be obtained by purchase, the width which was considered necessary for canal purposes being 280 feet.

The whole of the area occupied by the above space is situated within the boundaries of the military cantonment, the householders having no claim to the land, which they hold on the usual tenure as tenants at will; remuneration for value of property moveable or immoveable being paid for on the land being required for Government purposes, whether civil or military.

My estimate of 1850, for the value of property thus required, was founded on returns submitted by the executive engineer, whose data were necessarily imperfect, and who had neither the means nor the power of entering into details. The width of space was, moreover, under-

estimated, as well as the extent of building. During the cold weather of 1850-51, a committee which assembled for the purpose of determining the amount to be paid for a portion of the land required for immediate operations, closed their labours with a bill against the Government of rupees 67,167-7-5. The valuation was made very fairly; each house or tenement being measured, and the calculated cost of labour, as well as the probable value of material, being taken into consideration. The latter item was undoubtedly a high one, and founded on assumptions which were by me never expected to be realized, nor were they so in the result. Extravagant claims for materials in foundations which did not exist, assertions of undersunk wells in the proximity of the river, and varieties of demands for original expenditure of which there were no external traces, were received by the committee with a liberality that, as director of the works, and, therefore, as the guardian of the interests of the Government, I viewed with some degree of jealousy. The full amount of the claims, however, as recognized by the committee, was approved of by the Government, and the money has been paid with the exception of small sums for which at present no claimants (strange to say) have come forward.

In the cold weather of 1852–53, a second committee completed the settlement of the remaining property that came within the limit of the canal boundaries. This included certain estates or compounds formerly held by military officers, which had merged into the possession of natives, and which, by lying on the borders of the canal in the neighbourhood of the locks, were desirable as sites of mills and machinery. The arrangements made by this committee were similar to those of the former one, and the amount of the bill in this case was Rs. 22,898-9-0.

It was fortunate that within the area of the ground

which it was necessary to occupy, there were only two buildings for religious purposes. One a mosque (Mussulman), and the other a mundul (Hindoo). The position of these two buildings is shown in the map. Both of them have been allowed to remain, and although they interrupt the alignment of the works, they may be considered as in no way interfering with their usefulness.

I may observe that, in addition to the above payments, permission was given to the owners of houses to remove any fixtures for which they had a particular fancy. Carved wood-work, doors, and all ornamental work, whether of wood or metal, were not only carefully removed, but given gratis to the original owners.

The material, in fact, which was recovered from the buildings, and which, on their destruction, was carried to the account of the works, was singularly illustrative of my views, as to its value accorded by the committee. No indications of material swallowed up in foundations were discovered. The paucity of permanent or pukka buildings was remarkable, even to those who knew that native bazaars do not abound in structures of this description. With the exception of a very few so-called *pukka* houses, which, in their detail of construction, were, generally speaking, made of mud faced with brick, the whole of the bazaar that came under our clearance was a mere collection of mud walls, made from excavations in their neighbourhood, offering harbours for filth and stagnant water; literally nests of miasma, and reservoirs of offensive abominations.

It is worthy of record in how far the value of material procured from the bazaar and brought into use in the canal works, tallied with the estimated amount as paid to the owners by the Government. I shall merely give an abstract of the figures in this place, as I have noted in

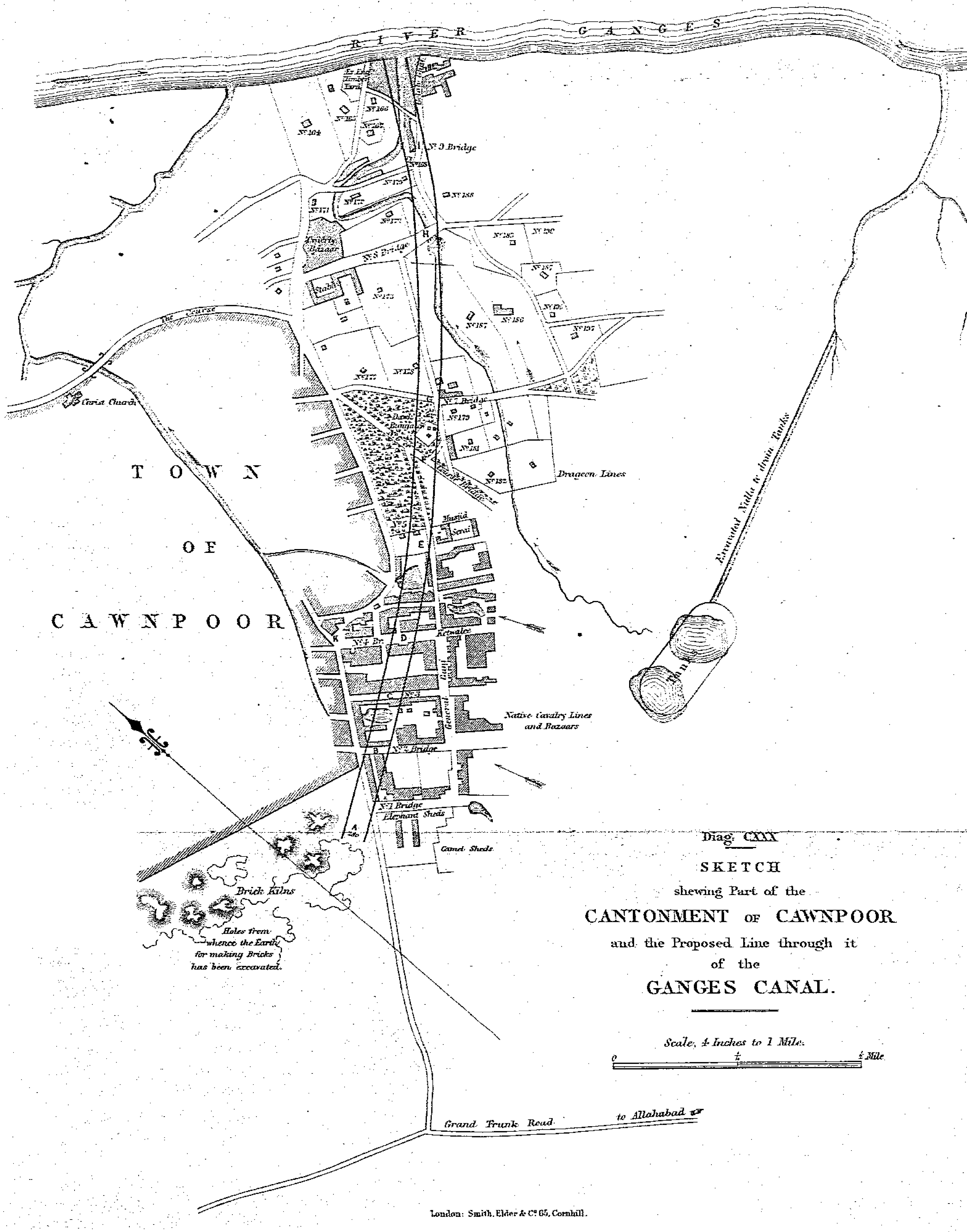
the volume of tables the whole of the detail, both in plan and figures, by which the estimate was arrived at.

	Estimated Value			True value of Materials.
	Labour.	Materials.	Total.	
	RS A. P.	RS A. P.	RS. A. P.	RS. A. P.
1st Committee	20,188 1 7	46,979 5 10	67,167 7 5	8,936 12 11
2nd Do.	Both		22,898 9 0	
	Totals, Co.'s Rs. . .		90,066 0 5	8,936 12 11

All the bricks that were fit for use were put into the canal works; the full price (and a very high one, too,) of *the market of the day having been paid for them in the* above table. The same may be said of the timber and other materials, those which were not given back to the proprietors, or those which were not required for canal purposes, having been sold by auction.

The total amount paid for houses and property which fell within the limits of the canal boundary, from the No. 1 Bridge (to which I have before alluded) to the junction of the canal with the Ganges, *i. e.* on a total length of 7,973 feet, and breadth of 280 feet, amounted to Rs. 90,066-0-5; a sum, it must be recollected, which *is totally independent of the cost of removal, clearance,* and preparation of the surface for canal excavation.

I have in the Second Part, Chapter II., Section III., explained my views on the Ganges Canal, in its connection with the town and cantonments of Cawnpoor, and have *shortly described the design of construction of the works.* I have also described the plan of esplanade, upon which I place great stress, as one tending much to the appearance of the canal, and more to the convenience and salubrity of the neighbourhood. I shall here enter into greater detail as connected with the buildings themselves, and with the whole *of the operations that took place during their construction.*



Diag. CXXX

SKETCH
shewing Part of the
CANTONMENT OF CAWNPOOR
and the Proposed Line through it
of the
GANGES CANAL.

London: Smith, Elder & Co. 65, Cornhill.

The plan on the opposite page is a fair representation of the ground with which the alignement came in contact. On its approach to the angle of the town upon which it impinges, it passes between the brick-kilns, to which I have before alluded, and the enclosures attached to the commissariat department in which the government elephants and camels are kept. This ground is much broken, being intersected by holes excavated for brick earth, which from the length of time during which material of this sort has been used and carried away, assumes at the present day the character of a series of lakes rather than holes, receiving as they do, not only the rain that falls upon them, but the drainage of extensive areas of land in their vicinity. Through one of the largest of these lakes, the canal channel passes just before it reaches the elephant sheds, not far from the north angle of which No. 1 Bridge is situated.

In advance of this point the natural drainage of the country takes a new direction. A tract of country which lies on the right of the canal over which there is a good deal of building, besides a considerable area occupied by open ground belonging to the cantonment, or cultivated land beyond it (the whole embracing an area of nearly two square miles), acts as a catchment basin. This is drained by two well-defined nullas, meeting each other in the town, and proceeding, after their confluence, in a deep channel which gradually becomes a formidable ravine. This nulla passes the church, and crossing the course, for which there is a bridge adapted to it, proceeds onwards (receiving other tributaries) to the Ganges.

This catchment basin is marked by numerous tanks or ponds, all of which, in that part where the bazaar is situated, are completely surrounded by huts and buildings, most offensive in every way, whilst those on the

open plains, although characterized by a comparative cleanliness, are, from their want of well-regulated drainage, a nuisance. The principal ponds of the sort alluded to are figured in the map, and it will be observed that the canal in its course through the bazaar passes through two of them. On all this portion of the line, the drainage crosses the canal alignement very nearly at right angles.

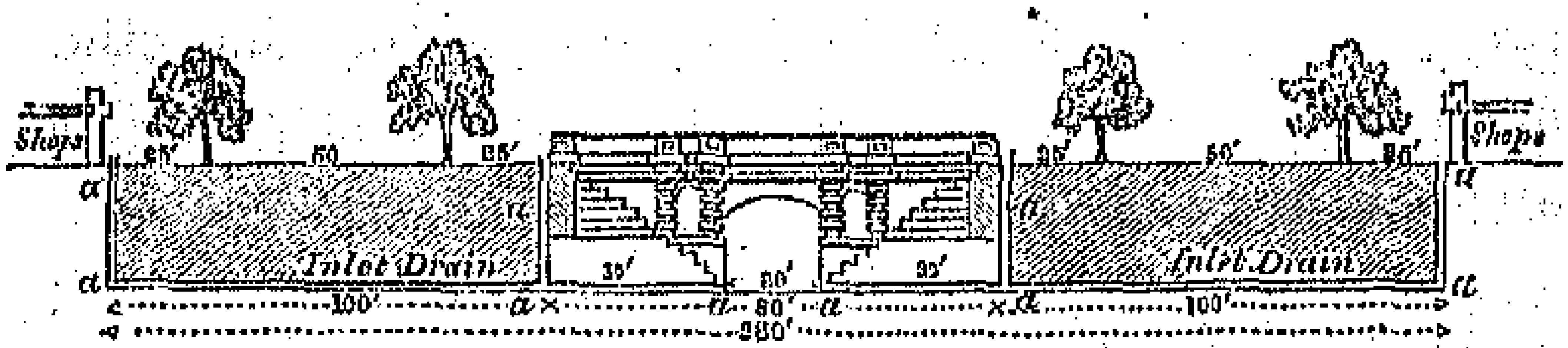
Proceeding onwards, on the line which we have taken up by the canal, it appears that a ridge upon which the Musjid (mosque) and Surai, noted in the plan, are situated, lies upon the water-shed of the church nulla, and that the opposite side of the slope sheds its water on a bearing nearly parallel to this nulla, but with a direction corresponding with the canal itself. Along this nulla, in fact, the canal channel is carried on the lower part of its course, and in company with it, joins the Ganges at the Gola Ghat.

The line of canal in its passage through the cantonments of Cawnpoor comes in contact with two distinct basins of drainage, both of which will be perfectly understood from the map.

The depth of digging from the point A, or from Bridge No. 1 up to No. 6, or the course bridge, averaged about 12½ feet. On this line, which extended over a length of 3,766 feet, the flatness of the surface admitted of the works being carried on on one level. The size of excavation, however, required for a channel 12½ feet in depth, with berms and slopes adapted to the quality of soil with which we had to deal, would have been inconveniently out of proportion to the width to which our boundaries were limited. I therefore determined on revetting the whole line with brick retaining walls, by which we should economize space by relieving the work from slopes.

The section that was determined on was shown in diagram 88, copy of which is for convenience of reference introduced here.

Diagram 181.



The design, in fact, was an esplanade, 280 feet in width, bounded on each side by façades of native bazaar, and having the canal channel passing down its centre. Bridges of cross-communication were to be adapted to the different streets that had been intersected by the works; and the spaces on the right and left were to be ornamented by four single lines of mangoe-trees, forming avenues extending on each side of the canal from No. 1 Bridge to the Ganges River.

My idea was, that these avenues, with the even and well-laid metalled road or esplanade on which they were placed, would become the general promenade, and, at any rate, the lungs and medium for ventilation of the town in their neighbourhood.

I have in the chapter above alluded to, referred to this as well as to the other objects which I contemplated in this line of works; the works themselves, however, are the subject of the present chapter.

From No. 1 to No. 6 Bridges, the ground being even, the works were laid out so that the esplanades or upper levels should be parallel with the canal bed, *i. e.*, on a slope of 12 inches per mile; between the two extreme bridges four others were built, each on the plan shown in Sheet 44 of the Atlas.

These six bridges, therefore, divided the whole length

of the channel into five separate bays, each of which had its retaining wall in the alignement of the bridge wing pillars, and its channel, fitted with either ghats (flights of steps) for the convenience of bathers, or with perpendicular revetments or quays for that of merchandize. The design of these different works will be understood from the plans.

Parallel to the canal channel, and in lines, one of which rests on the extreme canal boundaries, and the other on the back of the retaining walls of the berm, are a series of drains or bombas, dropping vertically into masonry channels, which are constructed at right angles to the canal. These drains are built in positions suitable to the wants of the neighbourhood, and it is supposed that they will give efficient drainage to all the town, bazaar, and land requiring it. The principle on which these drop drains are arranged with reference to carrying off the water from the high levels to those of the canal channel, is shown in the above diagram, *a a a a*.

The dimensions longitudinally of the different bridges and bays as mentioned above are as follow :—

			Feet.
A	No. 1.	Bridge	23
		Bay	573
B	„ 2.	Bridge	28
		Bay	626
C	„ 3.	Bridge	23
		Bay	587½
D	„ 4.	Bridge	23
		Bay	1,215
E	„ 5.	Bridge	23
		Bay	672½
F	„ 6.	Bridge	33
		Total length from up-stream side of Bridge A No. 1 to the down-stream side of Bridge F No. 6	3,822

On the left of the bay, and corresponding with the lower branch of the church nulla, an outlet with two openings of six feet wide each has been constructed, for

the purpose of giving relief on the occasion of heavy floods, as well as of acting at a convenient spot as a regulator for the supply of water upon the heads of the locks. This outlet is carried under the esplanade by masonry channels which pass off the water down the church nulla. Sluice gates for the purpose of regulating this escape are arranged at its head. They are on the simple construction adopted elsewhere.

The Bridge F, No. 6, which is built for the accommodation of the course road, is askew with an angle of 55½ deg. conformable to that at which the road crosses the canal.

Up to this point the evenness of the surface of the ground admitted of the works being built, not only on an almost direct line, but with their upper and lower levels corresponding. From the course bridge, a new order of things commences, the ground falls off in considerable slopes, and at a point 515½ feet from the down-stream side of the bridge, the drop of the first lock is situated. Although the same system of parallel revetted lines for both the channel and esplanades is continued, the irregularity of the upper surface necessitates a declination to the esplanades, so that whilst the canal bed continues on its uniform slope of 12 inches per mile, the esplanades or surface of the embankments are carried on in a succession of slopes corresponding with the drops at which the different locks are situated. On this line, moreover, the direction to which we were limited forced *upon us the necessity of continuing the curve, so that in* standing on the No. 6 Bridge we lose the perspective which a direct bearing upon the Ganges would have given us; an effect which would have been of material advantage to the look of the works.

From No. 6 Bridge, therefore, the esplanade and its retaining wall slope downwards on an incline of 1¾′ to 100′

for a length of 267 feet, at which point it meets the horizontal level upon which the lock buildings are constructed. The distance between the foot of the inclined plane and the *up-stream face of the bridge which crosses the lock* chambers is equal to 368¼ feet, and it is proposed that this flat should be used as a landing-place for goods on boats having reached the higher levels. In the immediate neighbourhood of No. 6 Bridge, flights of steps are built for communication between the high levels and the berm, and close upon the heads of the lock chambers are side channels for the supply of mills which are situated on the right and left beyond the limit of the 280 feet boundary. The waste, or escape channels of these mills, enter the canal below the bridge, and at a point free from the influence of lockage.

This bridge, which is called No. 7 G, corresponds with one of the main cantonment roads. It is built at right angles to and over the lock chambers, and has a roadway of 30 feet in width. Its total width between *the up- and down- stream faces is 33 feet (vide* Plate XLIV., Atlas).

At this place I may describe the locks; as, although in the detail of fixing and working the gates, in the plan and arrangement for the regulating sluices, and in the general dimensions of the chambers, they correspond closely with those which have been built on the main trunk, and which I have fully described in a former chapter, there are some differences in the lining out and general detail that are deserving of explanation.

In the first place, I required an ascending and descending series, so that boats might pass up from the Ganges at the same time that others passed down. I considered it to be a great advantage that even supposing the Ganges Canal was not available for navigation, the means of raising loaded boats from the low

levels at which the river runs to the higher, where the town and cantonment are situated, would be a great boon to the commercial community, and, *per se*, a very great advantage. Such arrangements might be made by properly economizing the water, so that even in drought, when irrigation carried off the greater part of the supply, a sufficient quantity of water would be available for purposes of the sort required, and although, after all, lifting boats by common water-locks is but a clumsy arrangement, and in all cases a very slow one, it is a very great improvement upon the existing method of unloading boats on the lower levels, and carrying the goods on carts or men's shoulders to the higher.

Again, not only to effect this purpose, but to give full means for regulating the supply at the head of the locks by apparatus fixed in the lock itself, it was desirable to design waste channels independent of the chambers, and in such a compact form that the object might be gained at the smallest possible outlay.

It will be seen, therefore, that the centrical wall separating the ascending and descending lock chambers, is perforated on its whole length with a channel 6 feet in width, fitted at its head with regulating apparatus. Into this channel the low level chamber sluices, with their *circular drum regulators, discharge the surplus water*, which passes off at the outlet at the lower end of the wall.

The drop at each of the locks is 9 feet, with a reservoir of 4 feet in depth at its foot. In front, and at a distance of 7 feet from the drop, a timber apron, for the purposes elsewhere described, separates the drop from the main body of the chamber, which is 112 feet long, inclusive of the lower gates. The width of the chambers is 16 feet. The detail of fixing and collars is precisely the same as that carried into effect on the main trunk.

From the down-stream face of No. 7 G or No. 1 lock bridge, a recurrence of a similar arrangement to that last described delivers the esplanade on No. 8 H Bridge; the canal bed continuing on its uniform slope of 12 inches per mile, whilst the top of the banks, for a distance of 285 feet 4 inches, are on an incline of $1\frac{1}{2}'$ in 100 feet; the total distance between the down-stream face of the upper, and the up-stream face of the lower bridge, being $1,543\frac{1}{2}$ feet.

No. 8 Bridge H passes the main street of the cantonment over the canal. Its width of roadway between the plinths of the parapets is 30 feet, and its total width between its two faces is 33 feet. This main street road has been much improved by the interposition of the present bridge, the elevation of which above the original levels relieves the road from an awkward depression which originally existed, and which was one of the great disfigurements of the main street. To effect this a good deal of earthwork was necessary in forming the approaches, and some masonry in securing effective drainage.

At this point the canal is fairly in the ravine or line of drainage, as shown by the map, and, as it will be observed by studying the longitudinal profile of the land with which it is connected, is mixed up with a quantity of broken and irregular ground, which required a great deal of artificial embankment and much care and judgment in laying it out. Great attention on the part of the engineer in executive charge was required in disposing of the drainage water, not only during the progress of the works, but in so adjusting the inlets that the water might be admitted in sufficient quantities to relieve the country, and at the same time by such gradual means that neither the canal works nor the country itself should be injured. This was most satisfactorily

accomplished by Lieutenant Hodgson; the greater portion of the drainage water which fed the ravine being turned off in a southerly direction, as shown in diagram 130.

From the down-stream face of No. 8 Bridge H to the head of the drop of the next lock, the distance is 852 feet; the canal bed being continued on a slope of 12 inches per mile. At the point where this descent takes place the fall is considerable, and it is disposed of by two locks in succession, each having a fall of 9 feet. The design of these works, being similar to those before described, needs no further illustration. At their tail, however, No. 9 Bridge I is thrown across the chambers in the same way as it is done in the cases before described, affording convenient cross-communication to the bazaars and houses in the neighbourhood.

The plan of overcoming the depression of the country on this line is effected in the same way as was described in the approach to No. 1 lock. The esplanade is carried on an inclined plane from the down-stream face of No. 8 Bridge, on a slope of 1 foot in 100 feet, to a point 631 feet below it; from whence the esplanade continues horizontal up to the head of No. 3 lock. From this point another inclined plane, on a slope of 7½′ in 1,000 feet, delivers the esplanade on the level of the roadway of No. 9 Bridge, which, as I have before said, crosses the tail of the lock chambers. The flats at the head of the locks are intended for the accommodation of loading and unloading merchandize.

Between these two bridges, No. 8 and No. 9, we were in contact with the old ravine, and on the down-stream side of, and close to the former, a deep hollow extending for 153 feet, with its bottom 12·2 feet below the canal bed, had to be filled in, and the foundations of the revetments had to be carried to a proportional depth.

On the approach to the head of the locks a good deal of ground had to be cut away to bring the esplanade on a uniform level. The whole of the ground, in fact, was a series of ups and downs, hills and hollows, requiring much care and pains in its adjustment.

At the head of the locks No. 2 and No. 3 arrangements have been made, by constructing outlet heads, for establishing mills or machinery, should such be hereafter desired.

The country drainage is on this line managed in the same way as it was before, and as is fully detailed in the sheets of maps.

We are now rapidly descending to the edge of the water of the Ganges, although (as I have before described as a peculiarity in the immediate vicinity of the river) getting amongst elevated mounds which, low as the level is comparatively with that which we passed in our progress through the town, is high with reference to the uniform series of descent by which the canal works are gaining the lower levels. Through these mounds cutting to a considerable extent was required, especially in advance of the works which I have just described.

From the down-stream face of No. 9 Bridge the esplanades are sloped downwards, until they meet the horizontal levels which continue up to the terminal buildings. These slopes have a base of 284¾′ to 9′ in height, and the length of the flat in front is equal to 503¾ feet, measuring from the foot of the slope to the extreme point in the curve of the semicircular ends. On this line No. 4 and 5 locks are situated, each with a drop of 9 feet, placed in close proximity to each other, as in the case of Nos. 2 and 3, and in dimensions and design precisely similar.

On this line there is no masonry bridge across the

chambers in consequence of the position of the flood levels of the Ganges during the rains, which it will be observed by reference to fig. 2, Sheet 5, Plate XLIV., stood 18 inches above the sill of No. 4 lock.

I have, in Part II., Chapter II., when reviewing the works on the Cawnpoor Terminal line, described the architectural features of the terminus on its Ganges face, showing how I have attempted to plan these buildings in harmony with others which, scattered along the edge of a richly-wooded bank, are so characteristic of river scenery as connected with towns and cities on the Ganges and Jumna. The lock-chambers are flanked by semicircular ghats or flights of steps, reached from the higher levels by stairs opening laterally from the higher levels of the esplanade. These lateral stairs are broken by a landing-place which gives the steps a direction to the front, and delivers them on the upper terrace of the semicircular ghats. On the right and left of these steps, and standing well above the terrace, are pedestals for the reception of sculpture emblematical of the Ganges River. Nundi's cow, which is one of the best of the Hindoo conceptions in the way of sculpture, being a cow in repose, although with its head erect, is the emblem that I proposed for these pedestals. Its face would be towards the stream.

On the flanks of each of the semicircular ghats are octagonal pavilions, consisting of domes supported on pillars. Each flank, therefore, of the lock-chambers is ornamented by two pavilions, with their intermediate flights of steps. Those of approach to the front staircase being flanked by the sculptured figures before alluded to.

The state of the Ganges River during high and low water will be understood from fig. 2, Sheet 5, Plate XLIV. of the Atlas; the extremes, as shown in this sheet, being 15·16 feet. During high floods, there-

fore, the lower, or No. 5 lock, would be entirely thrown out of use; No. 4, also, would only require the use of the gates for loaded boats on their drawing more than 13 inches; and for descending craft, the volume of water passing down the canal would, supposing it were four feet in depth, reach the high levels of the Ganges on a rapid which would render the use of the Nos. 4 and 5 locks unnecessary.

On the upper levels to the works just described, and on the flat below the No. 9 Bridge, houses for machinery might be erected. Water-power at this point would vary with the rise and fall of the Ganges, and during the rainy months, when the surface of the river arrived at its maximum, it would be either impeded or stopped altogether. Mills and other machinery, therefore, ought to be placed on the levels, on and above which No. 9 Bridge is situated. On all the upper line the back water from the main river would have no influence.

From the above description, with the plans before him, the reader will be able to comprehend the design of these works through their whole length, viz., from No. 1 Bridge, where the continuous masonry works commence, to their junction with the Ganges River. The total length is 7,973 feet, 3,822 feet of which has its esplanades on a level parallel with that of the canal bed; and the remainder, which includes the whole line through which lockage is carried, is in a succession of slopes and flats corresponding with the natural descent into the river.

As a general rule, the supersoil to a depth of 6 to 10 feet was found to be of a very tenacious quality, below which it was more or less sandy, in some places of unmixed sand. The foundations were laid in without any interruption from spring-water, and were, conse-

quently, of simple construction, and in unbroken lines of wall. The whole of the works have been built of brick masonry, generally speaking, with 12″ × 6″ × 3″ bricks, burnt in the neighbouring kilns, although the small native brick has been largely used, not only from the ruins of the old buildings that were purchased, but also from the puzawas, or native kilns. Good and well-burnt bricks, in fact, were taken without reference to their size, although the larger class was preferred, and was more generally brought into use.

I have devoted a sheet of the Atlas to the design for the foundations of the river front, which, as coming in contact with a lighter soil, and being directly in connection with the main river, required peculiar care and attention. On the face of this plan my working directions to the engineer in charge of the works will sufficiently explain the nature of the operations with which we had to deal. The superstructure, it will be observed, is founded on a series of blocks, undersunk in the way that has been elsewhere described. These blocks are carried to a depth of 12 feet, varying, however, with the nature of the soil that was met with in the course of undersinking. In front of the whole work, and facing the river, a protective apron of piles and heavy material has been given (similar to that which has been adopted wherever masonry work is in contact with a stream or current), as shown in fig. 1, Sheet 5, Plate XLIV. of the Atlas.

The rates at which the brick masonry was executed on this line of works averaged, per 100 cubic feet, Co's. rupees 16-14-3, the extremes being—

Rs. 19-10-8 for arch-work.
Rs. 14-1-10 for other kinds.

The difference depended on the species of work that was executed.

From No. 1 to No. 4 Bridges on the upper line, with a portion of the intervening revetments, were done under the management of Lieutenant C. W. Hutchinson, who in the first instance had charge of the works. The cement which was used at this time consisted of about equal parts of kunkur lime and bujree; the rate of masonry being, per 100 cubic feet, Co's. rupees 14-9-10. Lieutenant Hodgson, who succeeded the above-mentioned officer, and under whom the greater portion of the work was done, by having the lime burnt upon the works, and by putting a stop to the purchase of ready-made lime from contractors, introduced an improved material, which in my opinion has led to superior masonry. Lieutenant Hodgson's ingredients for cement were as follow:—

Three-sevenths kunkur lime,
One-seventh soorkee,
Three-sevenths bujree;

and his rate per 100 cubic feet of masonry was Co's. rupees 14-14-6.

The rate for undersinking the blocks is shown below. The work, however, was in progress at the period of my leaving India, and the rate, therefore, which I have given is consequently imperfect, in so far that it does not include the general averages of contingent expenses, which can only be made up on the completion of the work.

Cost of undersinking masonry blocks at the Cawnpoor Terminus, Co.'s rupees 7-2-0 per running foot.

II. *Terminal Works on the Etawah Line.*

None of these works had been commenced upon at the period of my departure (1854), and, as I have said in a former chapter, I would recommend their postponement until a future date, when the supply of water, and its effects upon the Cawnpoor Terminus, are better

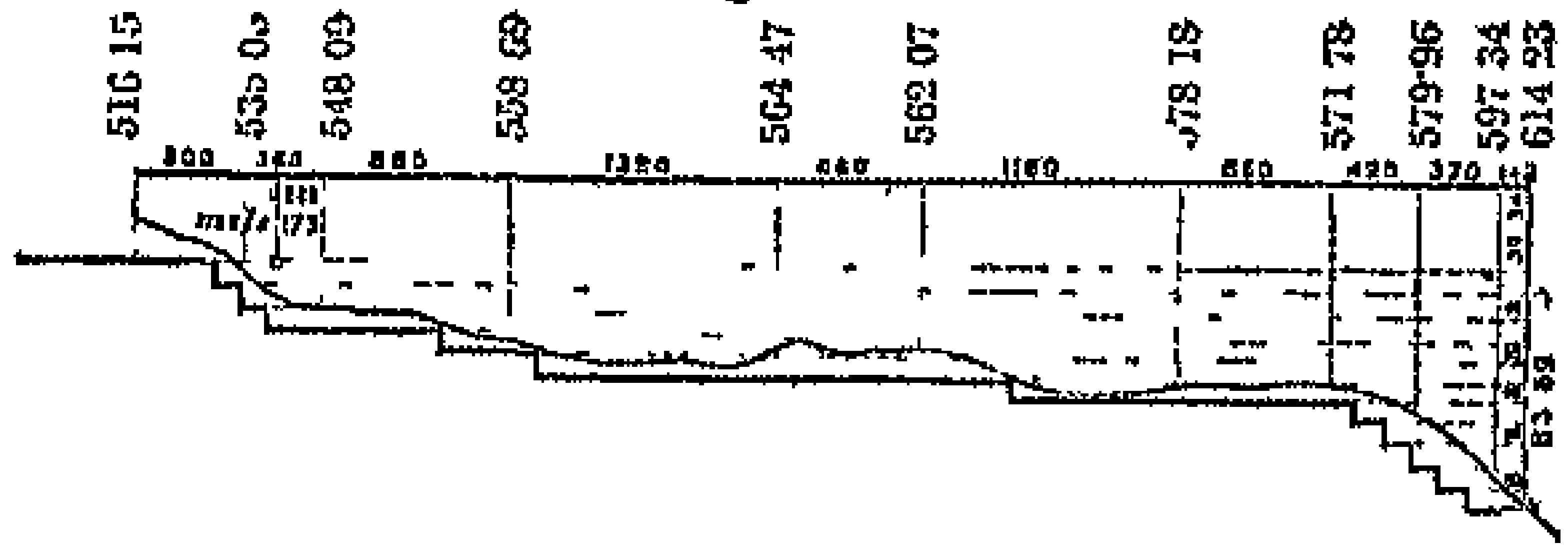
understood than they are at present. There can be no use in hurrying to completion works which cannot in all probability be required for many years to come. I would, therefore, collect all the imperishable materials, *e. g.* kunkur and bricks, necessary to carry on the buildings with vigour when lockage into the Jumna was desired; but as the progress of the works now going on on the Etawah line will not for a period of two years be advanced to the point where the terminal works are to be built, there is plenty of time both for consideration as to the period of their construction, as well as to their design. Of the latter, therefore, I shall content myself with giving the general views I hold on the subject, leaving the detail to my successor, who will be better able than I am to determine a plan for buildings appropriate to the desired object.

There are two points on which the Cawnpoor and Etawah termini differ very materially, and both of them are of great importance in any design that is projected. 1st. The Cawnpoor Terminus is in the midst of a town through which the canal channel passes, on a length of 7,973 feet, before it reaches the river. 2ndly. The slope into the Ganges at Cawnpoor is comparatively abrupt, the locks being at no great distance from each other, and all of them in a compact and regular series. The Etawah Terminus into the Jumna, on the contrary, is on an open country, separated altogether from towns or villages; and the high bank or commencement of the descent from the high to the low levels, is situated at a distance of 1¼ mile from the bed of the Jumna, the stream of which, at the period I am writing, runs on the Bundelkhund or opposite side of the valley, leaving a long tract of intermediate low ground between the first descent down which lockage will be required, and that by which access will be gained to the river itself. Here, therefore, will

be a long straggling line of works, instead of a compact series of buildings, as is the case on the Ganges, and here also, a less expensive design will be more appropriate. It must, nevertheless, be kept in mind, that if the supply of water in the canal is sufficient to afford water for navigation as well as for irrigation, and if there is sufficient water in the canal to keep a constantly running supply upon the locks, these buildings will inevitably become the nucleus of a town and the seat of a manufacturing *population, based upon the water-power which is* available on the high levels upon which these works are situated. Although, therefore, there may be no necessity for going into heavy expenses in ghats, mills, &c., in the first instance, we ought to hold these objects in contemplation, and be prepared for a period when, if necessary, they may be built in conformity with a comprehensive design of which the existing works would be the nucleus.

Under this view of the question, therefore, I would retain the plan of the ascending and descending series, or of the double line of chambers, as has been built at Cawnpoor; I would also adopt the method of waste and escape channels therein practised, but I would limit the extent of revetments, and be satisfied, for the present, with earthen slopes, thereby leaving full scope for improvements afterwards.

Diagram 132.



The above diagram exhibits in section the slope of country connected with the descent in approaching the Jumna River. There will be four steps, separated by

reaches varying from 600 to 2,000 feet in length. The design for passing these steps will be understood from plan No. 66 of the Atlas, which represents in detail the terminal nest of locks which deliver the canal water into the Jumna River.

III. *Termini of the Branches.*

A. *Futtigurh Branch.*—This is a work which is altogether prospective; it has been fully explained in Part II., Chapter III. At present the branch is designed strictly for irrigation, and it terminates at the 160th mile of its course in an escape which throws the tail-water into a line of natural drainage. The distance from the terminating point above noted to the Ganges River at Futtigurh is 21 miles, and as the total fall may be considered as equal to 41·19 feet, a series of lockage as I have proposed, viz., four drops of 8 feet each, with an intermediate slope of 5¼ inches per mile, so as to provide a moderate scour to the channel, would connect this branch with the town of Futtigurh, as well as with the Ganges River, which runs immediately below it. I have entered fully into this subject, however, in the chapter before referred to.

B *and* C. *The Bolundshuhur and Koel Branches.*—The former after passing through 80 miles of country, and the latter through 50, form a junction at a point not far from the town of Hatrass. From thence they proceed onwards in one united stream, under the name of the "Hatrass Line of Irrigation," through the country lying between the Seyngoor and the Jumna Rivers. This line terminates in the ravines on the Seyngoor River, or it may be carried over these ravines and form a junction with the Etawah Terminal on its approach to the Jumna. It is supposed, however, that at such extreme points, excepting during the rains, there will be no water suffi-

cient to render permanent works necessary; a point which experience only can decide.

I have, when describing the Bolundshuhur Branch, alluded to the possibility of a navigable line being taken from that branch to the Jumna, passing by the town of Belaspoor. This line would join the Jumna immediately below the confluence of the Hindun River, and might be convenient as opening out a line of traffic from a country richly cultivated to a river which, although not capable of carrying heavy craft during the dry months of the year, holds sufficient water for the easy passage of such boats as would pass down the canal; it would, in fact, connect the Bolundshuhur and the districts in its immediate neighbourhood with Delhi, Agra, and the towns lying on the banks of the Jumna.

PUTTRI WORKS, FROM THE NORTH.

CHAPTER IX.

SOLANI AQUEDUCT.

I SHALL consider the works on the Solani River which are discussed in this chapter, as divided into three sections:

I. Earthen portion, revetted, with terminal works, for the passage of the canal across the Solani Valley.

II. Masonry portion, for the passage of the Solani Torrent.

III. Bunds and embankments on the Solani River itself, in connection with the aqueduct.

I have in the early part of this paper explained the position that the Solani River holds with reference to the drainage of that portion of the Ganges Khadir with which the canal works are connected. It is in extent of catchment basin, dependent on our works for escape, by far the largest of all the torrents; the slope of bed, however, in contact with these works is comparatively moderate, but it meets us in a region of sand. The area of the basin lying above the works is equal to 216 square miles, its length may be estimated at 27 miles, and its average breadth at 8 miles. Of this area 50 square miles lie in the Sewalik hills, the remainder on rapid but gradually decreasing slopes, until it reaches the Ganges Canal works, where the fall in the bed of the river is 5·08 feet per mile.

The topographical character of this basin is exactly the same as that of the basins of the other mountain torrents connected with the Sewaliks already described.

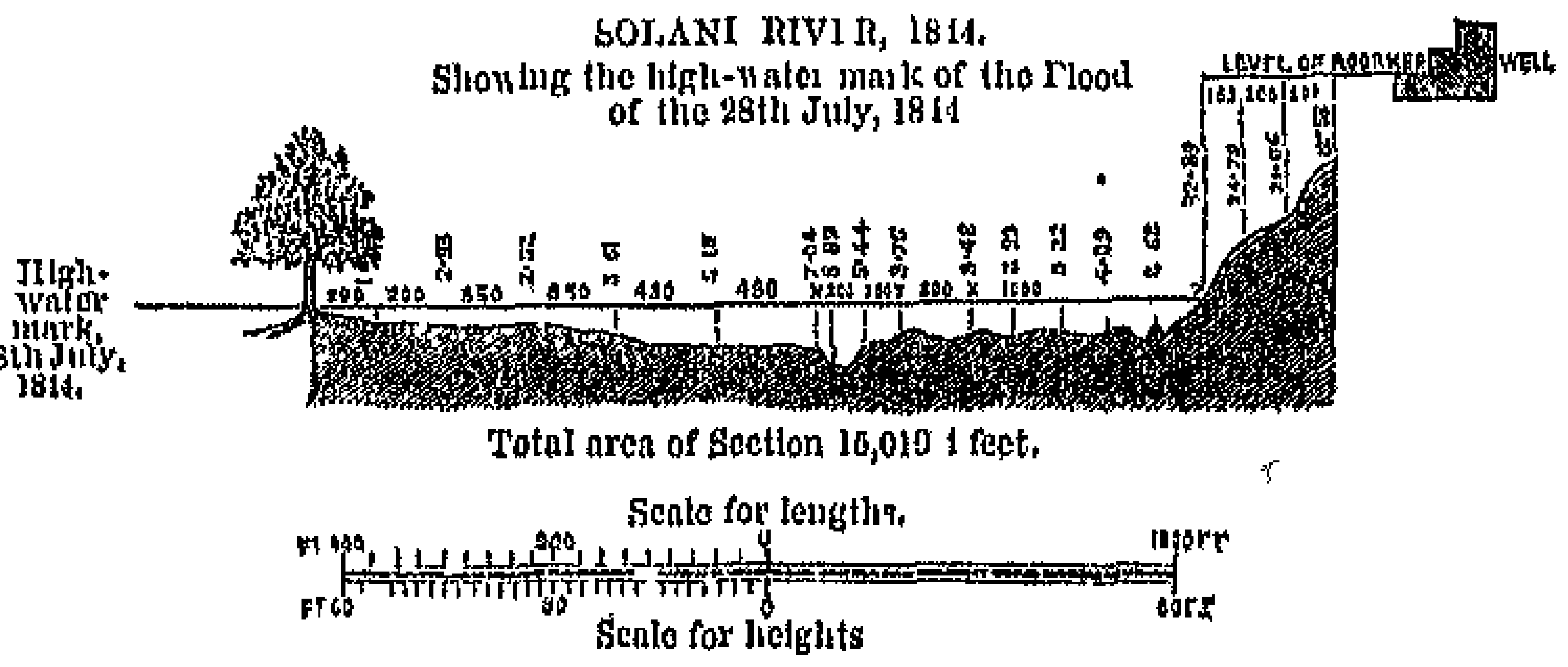
In the hills themselves, the tributaries and water channels that pour their supply into the main branches are distributed on courses so marvellously tortuous, and over ground so curiously entangled with ravines, that without visiting the top of one of the high peaks which are scattered along the ridge, it is hardly possible to appreciate the nature of the drainage, or to estimate the amount of area connected with these torrents. The aspect of the Sewaliks as viewed from an elevated point, is that of an extensive plateau, broken up by an entangled reticulation of fissures or ravines, the continuity of any single line being to the eye untraceable, from the inextricable confusion that appears to exist. True position of watershed can under such circumstances hardly be defined, and that above given, which is taken from the revenue map, must only be considered as the nearest approximation. The Solani Valley lies on the extreme west, and skirts the Bangor, or high land of the Doab, on its whole course to the Ganges. Its heads are on the watershed which divides the basin of the Jumna from that of the Ganges. The water that is shed on the western side comes in contact with the Eastern Jumna Canal works, *as connected with the Muskurra; that on the eastern* flows towards the Solani Aqueduct.

The Muskurra, as I have formerly mentioned, has great advantages in its elevated position with regard to the general drainage of the high land over which it passes. These advantages have been clearly discerned, and used largely in directing the torrent on lines bearing away from the canal works, by which the river itself on its coming in contact with the dam at Kulsoea is reduced to manageable proportions.

The Solani, on the contrary, which has a hill front equal to 12 miles, plunges at once into low land, and one of its main branches, which debouches from the well-

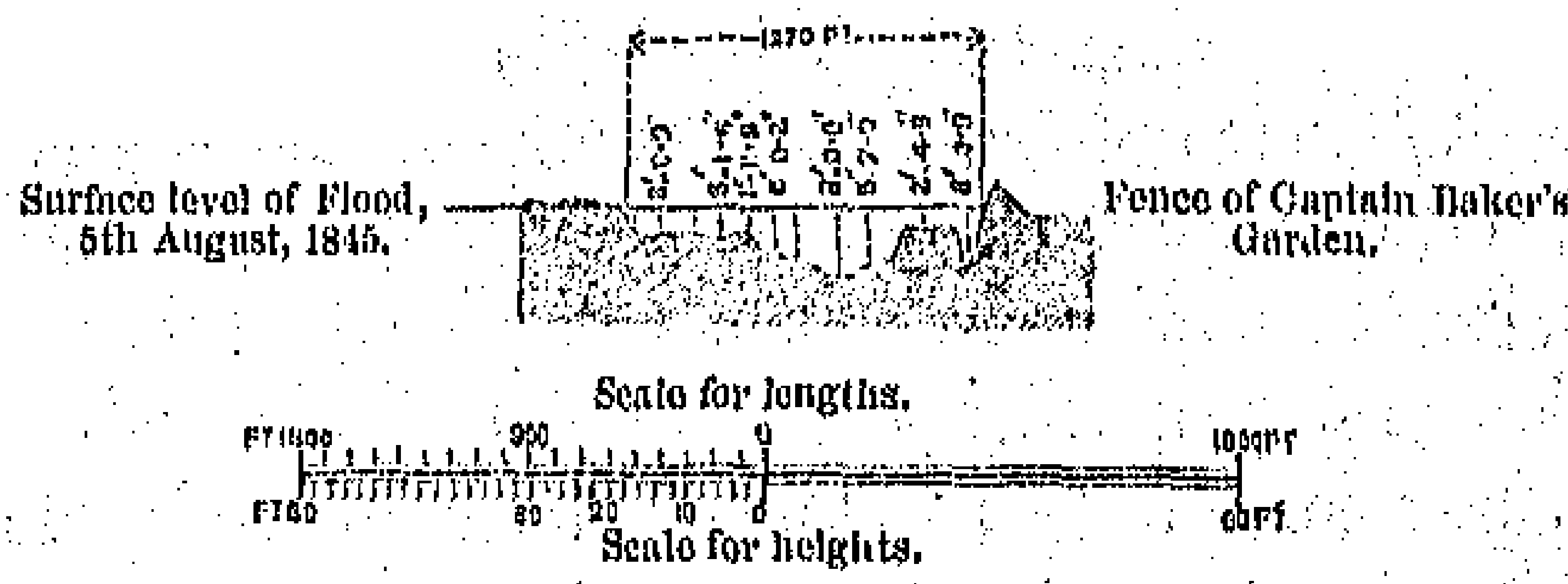
known pass called the Kheeri or Lal Durwazá (through which is a road from the plains to Mussoori and Landour), forms its junction with the main stream that proceeds onwards under the name of the Solani, just below the town of Kheeri and the high road from Saharunpoor to the hills. At this point the high land which forms the eastern border, and along the foot of which the Solani River runs, is 18 feet higher than the bed of the river; a command which is increased on its arrival at Roorkee, or at the site of the aqueduct, to 41 feet. There appears, therefore, to be a bar to any diminution of the volume of the Solani River, by throwing it upon other lines, as has been done in the case of the Muskurra. The heads of the West Kalli Nuddi, which lie to the west of Roorkee and Bhugwanpoor, appear to be the only available hollows for such a purpose, and their relative levels are opposed to it. It has, therefore, been considered as a matter not to be disputed, that the Solani River has to be dealt with in its integrity, and that, as in the case of the Rutmoo and Puttri torrents, we have no other resource than to meet each other by mutual accommodation. Without loading

Diagram 138.



this paper with registers of floods, the annexed diagrams, showing two of the highest on record since the year 1840, will give a tolerable idea of the extent of the Solani, and the amount of inundation dependent upon it during the rains.

Diagram 184.



The line on which the above section was taken is perpendicular to the stream, and was selected during the height of the flood of the 5th August, 1845. The above area appeared to be occupied by *running water*, the velocity of which was not measured, but was estimated not to exceed an average of five feet per second.

—	Area of Section.	Assumed mean Velocity.	Discharge per second.	Waterway of proposed Aqueduct up to level of Flood.	Calculated Afflux.
	Square ft.	Inches.	Cubic feet.	Square feet.	Feet.
Highest Flood, 1845 .	5,695	60·0	28,475	6,000	None.
Do. do. 1844 .	7,014	68·8	40,190	6,750	0·08405

Both these floods occurred previously to the commencement of the aqueduct works, and before obstruction in any form had been placed in the way of the water. The value of the calculations may be estimated by the remarks appended to the diagrams. The section of 1844 was taken somewhat obliquely to the course of the river, and in both cases the calculated discharge I believe to be in excess to the true one.

The valley or khadir through which the branches running from the hills pass up to their confluence below the town of Kheeri, is almost entirely forest, of that order which is peculiar to the southern foot of the Sewaliks, composed in a great measure of kyr (*Acacia catechu*), with low growing shrubs, dotted here and there with bur, peepul, and other gigantic trees, which are by no means numerous. The land in the immediate neighbourhood of the hills is shingly, and more or less marked by boulders, obtained from the degradation of

the super-strata of the Sewaliks, which consist of shingle beds. On the lower tract it is clay and sand, much intersected by lines of drainage. The boulders and shingle cease before the branches reach Kheeri.

Below this junction, or below the confluence of the different branches which are connected with the Sewaliks, the Solani runs in a straggling course between the high isolated mound which separates it from the Rutmoo, and the elevated land on the right. At some points it shows a well-defined section through clay of a very tenacious quality, at others and generally speaking, it wanders about on a tortuous course through the low land or khadir, which during geological periods it has provided for itself. Here the bed is universally sand, although in the few cases where the river runs in a confined channel, the banks and bed are of clay. A very good section of the latter description will be found at a distance of 8,500 feet from the up-stream side of the aqueduct, where the river during its highest floods appears to pass through a well-defined channel, without lateral inundation of any sort. At the site of the aqueduct the course of the river was tortuous, with a sandy bed depressed about 4 feet below the surface of the valley, which on its whole extent below Kheeri is more or less cultivated with wheat and other cold weather crops.

It will be understood that the high land bordering on the Solani Valley between Kheeri and Roorkee throws a considerable quantity of drainage-water into the valley; this is effected on the right by well-rounded off ravines, some of them extending a mile into the country, and connected with land of a very undulating character. On the left, or from the isolated high land which I have called the Peeran Kulleeur ridge, the same species of drainage takes place, varied, however, by two lines of considerable importance as exhibiting collective drainage, the one between

the towns of Sukrouda and Imli, the other rising near the village of Goomawalla; the former was one of the impediments that offered itself to the circuitous line which was the alternative in crossing the Solani Valley; the latter, which I have called the Imli Nulla, as it passes to the east of that town, joins the main torrent at a point about 7,200 feet above the aqueduct. I may observe that in estimating the value of the catchment basin, I have included one mile in width of the high land lying on the right, and the whole, or nearly the whole, of the Peeran Kulleeur ridge, which lies on the left of the Solani Valley, as ground which sheds its water into the Solani River.

A peculiarity which is an attendant feature on all these khadir rivers when bounded by high banks, viz., the existence of nullas parallel to and close under the banks themselves, is here, as elsewhere, remarkably prominent. They exist both under Roorkee and under the villages of Muhewur and Bajooheri, or those lying on the right and left of the valley. They are crossed at its intersection by the aqueduct.

In the chapter devoted to the dams, in which the detail of the Rutmoo River and its works is given, I have explained that the line of canal on its change of direction at those works, proceeds on a direct bearing through the Peeran Kulleeur ridge to Roorkee. This bearing is 218·36 deg.; it is unbroken, the axis of the regulating bridge at the Rutmoo or Dhunowri works, and that of the Roorkee Bridge, which is situated at the down-stream terminus of the aqueduct, being one.

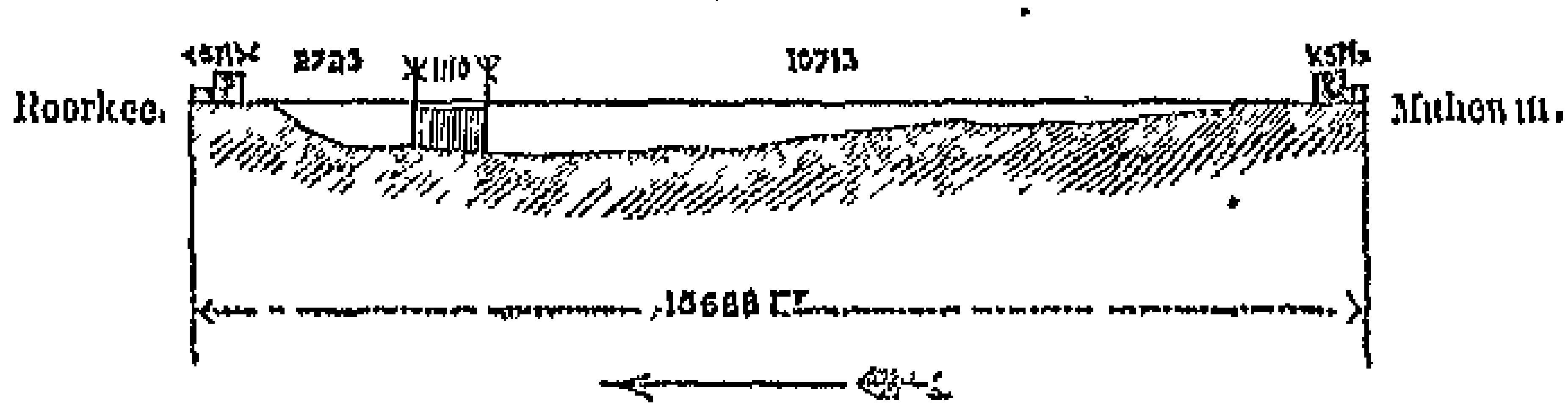
The surface level of the country on the line now taken up by the aqueduct, is shown in the longitudinal section or profile, Plate LXIV. of the Atlas. The alignement touches the valley first between the two villages of Muhewur and Bajooheri, and reaches the opposite side close upon the east of the town of Roorkee. The width

of this valley between the points where the true bed of the canal intersects the high banks on its right and left, is equal to 13,265 feet, or a little more than $2\frac{1}{2}$ miles. Its maximum depression below the canal bed is 24, and that below the surface of the country is 41 feet.

The aqueduct consists of a masonry channel carried over the Solani torrent on a series of 15 arches of 50 feet span each. This masonry channel is connected to the high land at Roorkee and Muhewur by an earthen channel, flanked by revetments built in the ghat or step fashion. These revetments are backed by wide embankments, the upper surface of which is 30 feet in width, with exterior slopes of $1\frac{1}{2}$ to 1. The earthwork, both of the canal bed (which from the above explanation it will be understood is considerably raised above the valley) and the embankments on each side, is made with great care and well consolidated.

The longitudinal dimensions of the works on this river will be understood from the following diagram:—

Diagram 135.



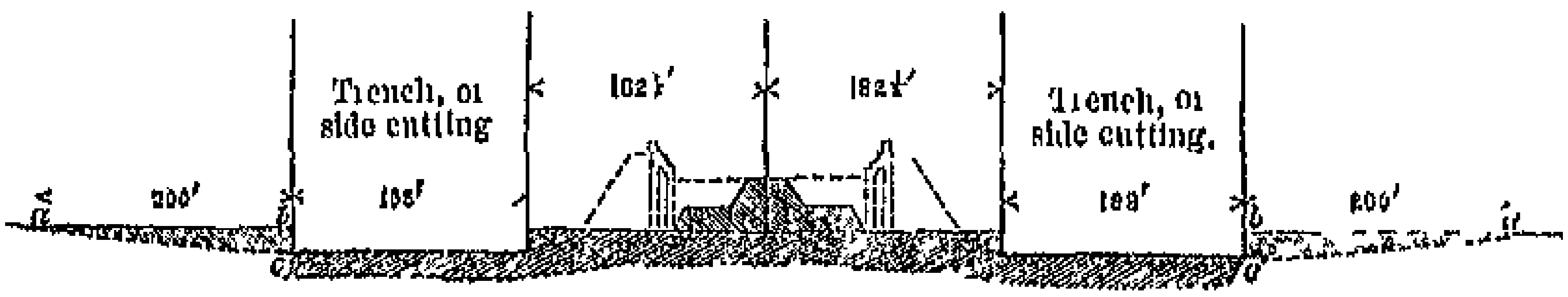
With these prefatory remarks, which will explain the general character of the river, as well as the nature of the work which has been designed to effect its passage, I may take up the detail seriatim, commencing with—

I.—Earthen Aqueduct, with Masonry Revetments and Terminal Works, etc.

This was the first portion of the aqueduct works which was undertaken. The commencement was made

in the cold weather of 1845–46 on the left bank of the Solani River, and in low ground between it and Muhewur. The work at this period consisted of excavating trenches on the right and left of the aqueduct line, and throwing the earth on the centre, so as to form a nucleus for the raised embankment which was to constitute the bed of the canal on that portion situated between the revetments. The lining out upon which this work was executed was as follows:—

Diagram 136.



The trenches were 188 feet in width, and carried to a depth of 5¼ feet, the earth being placed in contact with the axis line above shown, and in such a manner that it should not interfere with the building of the revetments, the lining out of which was not perfected until the beginning of 1848. The earth obtained by the means above described, although by no means inconsiderable in amount, was small when compared with that required. It provided, however, a good foundation upon which superstructure might afterwards be raised. The earth itself, as taken from the surface, was tolerably good, and in 1848, on my rejoining the works, I found the whole in a very satisfactory state of consolidation.

At the same time that the work above explained was in progress, the canal channel at Roorkee was going on. Here a commencement was made on the edge of the high land, and the earth was carried out into the valley by wheelbarrows moving from a high to a lower level on a continuous line of planks, the distance to which the earth

was carried by these means being from 200 to 300 yards, and the labourers who were employed being able-bodied men, receiving as monthly pay 4 rupees. Major Baker—who at the period that I am now describing was directing the progress of the works—in writing to the Military Board on the 22nd August, 1846, observes, that the work above alluded to may be considered to have been executed under favourable circumstances, and "yet the rate of earthwork averaged from 3 to 5 rupees per 1000 cubic feet, increasing rapidly with the distance to which the earth was conveyed." Major Baker, in pointing out the necessity for using rails and waggons on the northern side of the aqueduct, or that near Muhewur, and showing that the whole of the earth beyond that already excavated in the side cuttings must be brought from the canal channel excavation in the Peeran Kullecur ridge, recommended that my agency should be employed for the despatch from England of the ironwork required for a certain number of waggons, and that no time should be lost in the arrangements which had been formerly proposed of obtaining from England the services of artificers, and men practically acquainted with timber and ironwork. As early, therefore, as 1846, preparations had been made for supplying the works with means of transporting earth from the distant cuttings. In the meantime, however, the progress of the works was delayed by a variety of circumstances, which have been detailed in the first part of this report; and although nothing was carried on with vigour until very shortly before my return to India, I found on my arrival at Roorkee, a considerable number of waggons ready for use, with much preparatory information on the economical practice and construction of tram or railroads as adapted to the particular duties for which we required them. My duties, therefore, were comparatively easy, and confined, it may be said, to

working out the design, and carrying out such improvements as experience showed to be necessary.

On my returning to Roorkee and relieving Major Baker from the directorship, the state of the works may be thus described. The trenches on the left, or north of the aqueduct, were very nearly completed, and the earth was placed in position, as shown in diagram 136; a temporary or service bridge had been thrown over the nulla or line of drainage which I have described as skirting the valley on the Muhowur side, and which was intersected by the aqueduct embankments. The object of this bridge was to afford a passage or means of communication on the level of the valley for carts and labourers, and on the higher levels for the ballast waggons when carrying earth. The bridge was situated on the axis of the aqueduct, as figured in the above diagram.

On the right or Roorkee bank of the Solani, a portion of the side revetments had been completed on a line of 100 feet, and a considerable portion of foundations and archwork had been done and was in progress in the vicinity of the completed portion. Earth had also been excavated and carried, as I have above described, in wheelbarrows, to the space between the revetment walls. Lieutenant Yule, who at that period was executive engineer in charge of the works at Roorkee, was also engaged in laying out the alignment of the side revetments between Roorkee and Muhowur; a work requiring great skill and careful observation, the direct line upon which the walls were to be carried being upwards of 2½ miles in length.

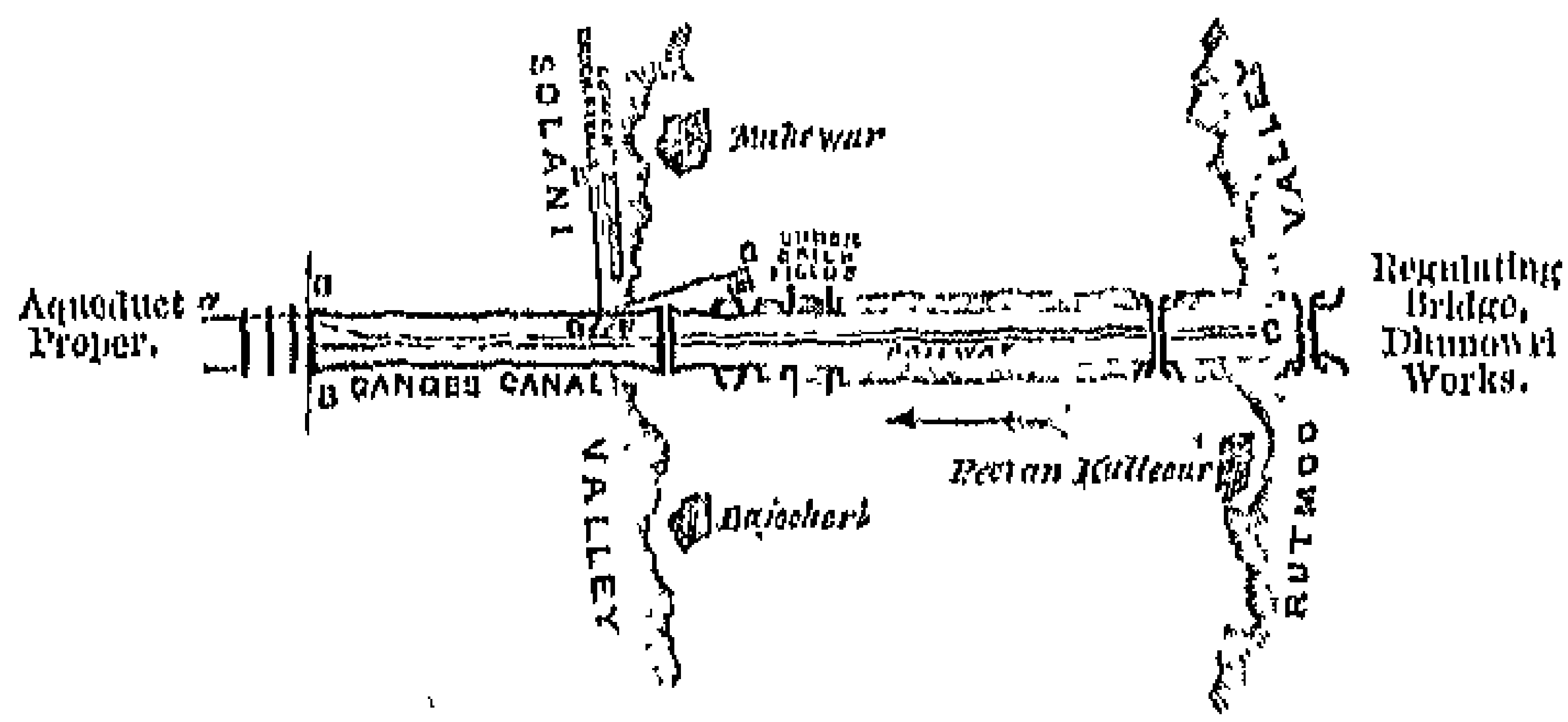
Captain Goodwyn, who relieved Lieutenant Yule on the 15th of April, 1848, and Mr. Finn, who a short time previously to my return in January, had been appointed to the Material Department, commenced at this period to

organize a system of railways, connected with the brick manufactories which had been established at Roorkee and Muhewur, that is to say, at each end of the aqueduct. The railways were necessarily a main feature in the earthen aqueduct, as it was through their aid that the embankments would be formed. The first part of our operations, therefore, consisted in laying out the brick-fields in a uniform shape, with lines of rail running parallel and close to the kilns; these formed branch or second class lines, which were connected with the first class, laid along the axis of the main canal. The former were single, the latter double lines of railway. The branches were confined entirely to the carriage of bricks or material from the manufactories; the main line was for transporting earth from the channel to the embankments, which in viaduct fashion were pushed forward into the valley, the railways being extended at their termini, in proportion as the work on the excavation and the embankment advanced in progress.

On the left or Muhewur side, the direction of the slope of the railway corresponded with that of the canal and the natural flow of the water. A commencement to the railroad, therefore, was made at a point near Muhewur; the line was carried on a slope of 1·5′ per mile centrically on the canal channel, and earth excavated from the Peeran Kulleeur ridge was pushed out, and the line progressively advanced until it reached the Solani River, or the point where the earthwork terminated on the masonry aqueduct. The gradient of the rail was 3 inches in excess of that of the true bed of the canal, and consequently obtained at its extreme terminus a depression below that of the true bed level. With this main centrical line two branches were connected, one leading to brick-fields and lime warehouses, which were situated on the high ground, the other to the great brick

manufactories under the Muhewur village, and on the slope of the bank bordering on the valley. The former, 2,050 feet in length, was obtained by some moderately deep cutting, and was brought upon the main line by a curve of 800 feet radius on a gradient of 1 foot in 133 feet. The other was a heavier work, as it had to be carried from the canal bed on rather a high level, over some very low ground lying on the outside of the embankments. Over this piece of low ground a temporary bridge was constructed, and the railway, which was carried over it on rather a sharp curve, was pushed forward on an embankment raised to a mean height of 20 feet from the ground, and in a direction parallel to and at a distance of 100 feet from the line of brick-kilns. By this arrangement, although we had more difficulty in loading the waggons, we avoided the greater difficulty of a steep incline, and by the rail being elevated there was no interruption to communication, foot passages being made

Diagram 137.



References.	Distance.
B C. Main line, extending from left abutment of the aqueduct, through the Peeran Kulleeur ridge, to the Rutmoo valley	20,853 feet.
D E. Branch line to lower brick-fields	2,500 „
F G. Do. upper do.	2,050 „
a. Muhewur material line across aqueduct cutwaters	1,120 „

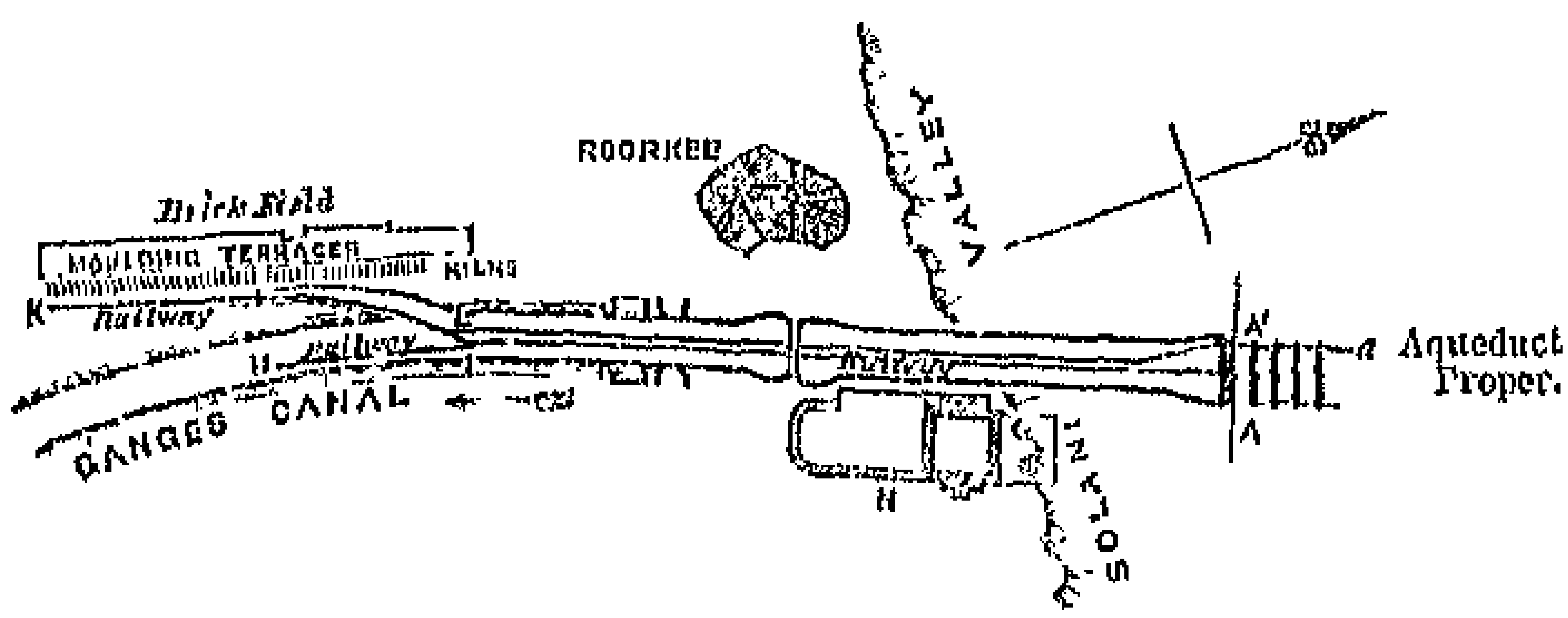
through the embankment and under the rail at fixed distances along the whole line. From the sharpness of the curve at the point where the railroad crossed the service bridge, it was found necessary to raise the bars

on the concave or outer side 3 inches above those of the inner. The length of this line was 2,500 feet, on a gradient of 1 in 250.

The direction of the railroads on the Muhewur side will be understood from the preceding diagram.

On the right or Roorkee side, after completing the flooring and foundation of the bridge, a similar line of railroad was laid down from the bridge towards the valley. As the direction of the required gradient was opposed to that of the canal bed slope, the position of the rails at the bridge was raised so that the road, when it came in contact with the masonry aqueduct on the point where the earthwork terminated, might coincide in level with that particular point. This can be best described by a diagram representing the different lines of rail as connected with the Roorkee side, during the progress of the works.

Diagram 138.



REFERENCES.	Distance.
A H. Main line for carriage of earth	6,355 feet.
K A a. Branch line for the carriage of materials, extending across cut-waters of aqueduct, and meeting the Muhewur material line . . (Distance from K to A', 5,567 feet.)	6,700 „
K L. Line connecting brick-fields with branches	1,330 „
L A'. Branch for supp y of bricks to works	3,057 „
K L I. Brick-field branch	1,380 „
N. Workshops.	

The gradient of the brick-kiln line on K A′ a, north of the Roorkee Bridge, was 1 in 208; south, 1 in 200. That of the excavated line H A was 1·25 feet per mile.

The above, although somewhat anticipating events, when describing our early operations, will show how

the railroads gradually got into proper form. The main line A H, which is continued on one uniform gradient, so as to deliver the earth on the highest levels required for the bed, stood during our early progress on a very elevated position; whereas its parallel line A′ L, which was specifically designed for the carriage of bricks from the kilns to the works, was depressed, so that at the point A′ it touched the levels of the cutwater heads of the aqueduct proper, along which it was carried, ultimately, across the river, and joined on to a branch taken from the main trunk line on the Muhewur side of the embankments. As the work advanced in progress, therefore, the termini of the aqueduct, and the works at Muhewur and Roorkee, became connected; a bond that was more closely tied on the completion of the arches of the aqueduct proper, when the main trunk was carried across, forming a line of railway from Peeran Kulleeur to the Roorkee kilns.

The first rail that was laid down consisted of bars of flat iron, varying from ½ to ¾ inch in thickness, screwed upon longitudinal sleepers, which were held in position by cross-bars or transoms. These, in fact, with certain modifications and improvements in ballasting, scantling of wood used, and method of fixing the bar upon the sleeper, have been used very successfully throughout the whole of the operations. They were subject to a good deal of wear, and were more difficult to retain in position than the English rail which was introduced in 1850; but they did their duty efficiently, had the merit of cheapness, and of being easily replaced by purchase from the neighbouring markets. In 1850, however, 30,000 running feet of light rail bars, which had been selected in England by Major Baker, arrived at the works; they were of that variety denominated bridge rails, weighing 26 lbs. to the yard, and the method by which they were

fixed on the woodwork was much the same as that adopted in the flat iron, that is to say, in longitudinal sleepers with cross-bars. At this period, however, we had found it necessary to give additional thickness and massiveness to the sleepers and woodwork in general, and the ballasting was made of a better and more expensive species of material. The superiority of the rail over the bar was sufficiently recognized by the purchase of a further supply of the same sort as that first received, giving us a total length of 60,000 running feet, which, with the tramroad, supplied us with all that was required both for the works at Roorkee and Dhunowri.

As the whole of the earthwork connected with these railroads naturally fell into the cost of embankments, and was included in their expenses, it is difficult to give a precise return of the actual cost per mile of the different species of roads made upon these works. On both the Roorkee and Muhewur double lines, where flat iron bar was used, the cost of iron, timber, with all the necessary apparatus for fixing, including labour employed up to the period when the waggons were placed upon them, was as follows:—

Muhewur main line, double railway .	Co.'s rs.	18,974-12-8 per mile.
Roorkee do. do. .	,,	18,760-12-2 ,,

The work at each place was carried on under separate European supervision, and the accounts, as rendered to the executive engineer of the works, were quite independent of each other. The returns on the two lines correspond so closely, that they may be looked upon as fair rates of this species of railroad. Here, however, it is distinctly explained that, as far as earthwork is concerned, the above rates merely include the consolidation of the earth. The excavation, carriage, and laying out of the said earth, as well as of the ballasting, being charged to the embankments, of which it forms a component part.

The above rates appear to be verified in a great measure by the cost of a single railway at Roorkee, where there was no embanking, but where the sleepers were laid on the earth with little or no artificial ballasting further than was required to maintain the woodwork in position and to keep the rails steady. A mile of single rail laid down under the above circumstances cost Co.'s rupees 8,809–9–4. The work was required for waggons which were during the whole of the working day passing backwards and forwards loaded with bricks, and although clearly inadequate to permanent work, was quite sufficient for the purposes for which we wanted it.

The cost of railroad, where English rail was used, varied very little from that above described, with exception to the cost of the iron. This, in the case of the flat bar, as purchased from the markets, was delivered at Roorkee at a cost varying from rs. 1,700 to rs. 2,100 per mile of single line; whereas the English rail, when it reached Roorkee, stood us in rs. 2,575, for an amount equal in extent to the above distance.

The wear upon the wheels and flanges was greater in the case of the flat bar than in the English rail; the surface for friction of the former being not only much greater, but much more uneven. I can compare the difference of motion in travelling over lines made of flat bar iron, and the bridge rails which have been used on these works, to nothing better than that of unmetalled and metalled roads. Comparatively speaking, they bear the same value to each other; the wheel in one case running awkwardly and with constant jerks, whilst in the latter, or English rail, it passes on evenly and steadily.

Plans and sections of the different railroads, with the wood and ironwork connected with them, will be found in Plate XXVII. of the Atlas.

Previously to my reaching Roorkee, a number of

small waggons had been made up with side doors and without tilting apparatus; these gave us the early means of commencing our earth-carrying operations. I had, however, brought with me from England tracings of what I thought to be the waggon best adapted to our works, with the ironwork of one waggon complete. A waggon, therefore, on this plan was immediately placed upon the work; its tilt was to the rear, similar to those which, during my residence in England, I had seen universally employed on railroads, and which were convenient from throwing the earth forward in pushing on embankment across a valley. This rear tilt, however, did not appear to be applicable in our case. The embankments in England are made little more than the width of the sleepers on which the rails are laid; the rear tilt, therefore, throws the earth in the position in which the railway engineer requires it. In the Roorkee works, after the line of railroad was completed, the rear tilt became useless, as we required a waggon that would empty the earth on the right and left of the line, from whence it could be spread out on an extended surface, which the form of the aqueduct rendered indispensable. The rear was, therefore, changed into a side tilting waggon, upon which plan the whole of our carriages were ultimately made up. I have, in Plate XXVII. of the Atlas, given drawings of all the waggons that have been used. Sheet 20, figs. 1 and 3, or that which was made first of all, is cheap, and, as far as first cost went, the most economical; its want of tilt, and the small quantity of earth that it carried, weighed strongly against its further adoption; this species of cart, therefore, was discontinued after those which had been originally made up were worn out. The only modification that the cart in question required, was the prolongation of the side doorways to a point beyond the wheels (*vide* figs. 2 and 4,

Plate XX.), so that in unloading the cart the earth might not interfere with the rails. Before this alteration was made, the earth, on the opening of the side door, fell upon the rail directly between the wheels, thereby preventing the movement of the waggon, and causing interruption to the passage.

The cost of one of these waggons, including the wheels and axles, which were received from Calcutta, was rs. 289-9-5.

Plate XXVII. Sheet 21, or the ballast waggon, the plan of which I brought from England, has, as I have before said, a rear tilt, and in other respects as well as this, is similar to those of English railways. For the reasons above given, only two on this plan were made up; they did their duty well, but, as I have before explained, they were not well adapted to the work. The cost of each was rs. 438-1-3.

Plate XXVII., Sheet No. 22, is the standard plan upon which all the waggons in general use have been made; it has a side tilt, is very strongly put together, and carries a load equal to 50 cubic feet. Of these 450 have been employed either on the works at Roorkee, or those on the Rutmoo River at Dhunowri. The cost of each averaged rs. 358-0-4.

Having explained the lining out and design upon which the embankments were to be made, and having described the material at our disposal for carrying on the operations of the earthen aqueduct, I shall now proceed with a detail of progress from the commencement to the completion of the work, as made by Mr. James Parker, the assistant engineer, who was placed on this specific duty under Captain Goodwyn.

The state of the earthwork on the commencement of progress by railroad at the beginning of 1848, will be understood by a reference to diagram 136, and to a

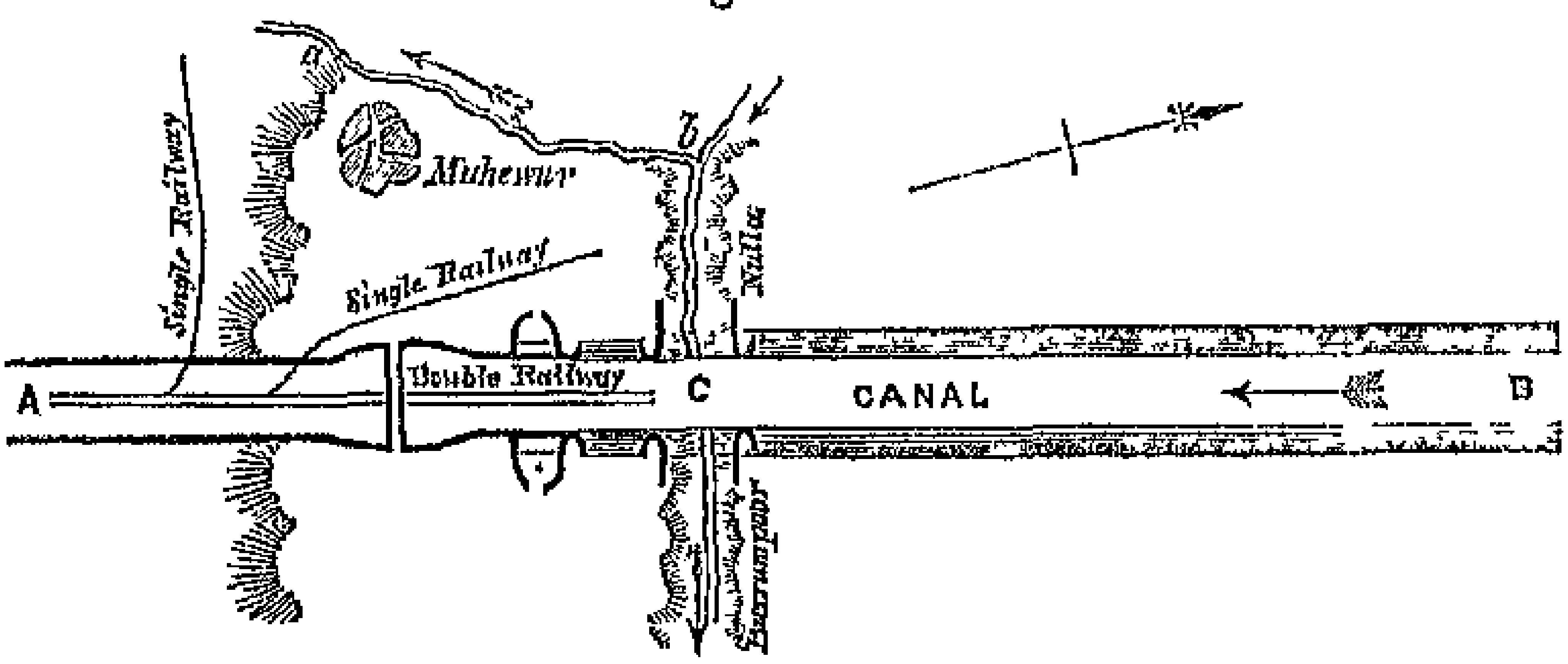
former paragraph, in which I have mentioned that, independently of the side cuttings figured in the diagram alluded to, and which were confined to the Muhewur side of the valley, earth had been thrown out from the channel excavations on the Roorkee side. This work, having become well consolidated, acted as the nucleus for Mr. Parker's railways, which were started in the first instance from Muhewur. At this place, as far back as 1846, accommodation, in the shape of a choki building, had been constructed for European supervisors, and other necessary cover for lime, and workshop purposes. Ultimately, stabling was completed at different subsequent periods. The duties of the engineer at this point included masonry as connected with the side revetments and terminal works, as well as earthwork in raising the bed of the canal, constructing the embankments in rear of the revetments, and (as the earth for this purpose was taken from the canal channel on the line between Muhewur and Peeran Kulleeur) in completing the canal as far back as the Rutmoo valley.

The general design of the aqueduct will be understood from the plans in the Atlas. Its total length from one extremity to the other is 15,688 feet, independently of the masonry escapes attached to the up-stream terminus, which, having been constructed for purposes which in all probability may never be required, and which are, in fact, embedded in the embankments, are not included in the above measurements.

These escapes, which consist of a masonry flooring 100 feet in width, placed on a level 12 inches below that of the canal bed, with flank walls, are in immediate contact with the up-stream terminal ends of the aqueduct. They lie on both sides of the canal, and are in connection with a hollow or ravine, which in the description of my original survey was shown to cross the line of canal at

this point. This ravine was the outlet of the Burrumpoor nulla, which, commencing in the high land on the west, terminated in the Solani valley, under the village of Bajooheri, immediately on the east of the canal. The nulla was disposed of by a cut carried to the west of Muhewur, so as to turn its flood-water into the valley before it reached the canal boundaries. The topographical character of the ground at this point will be best explained by a diagram, in which the up-stream terminus of the aqueduct is introduced.

Diagram 139.

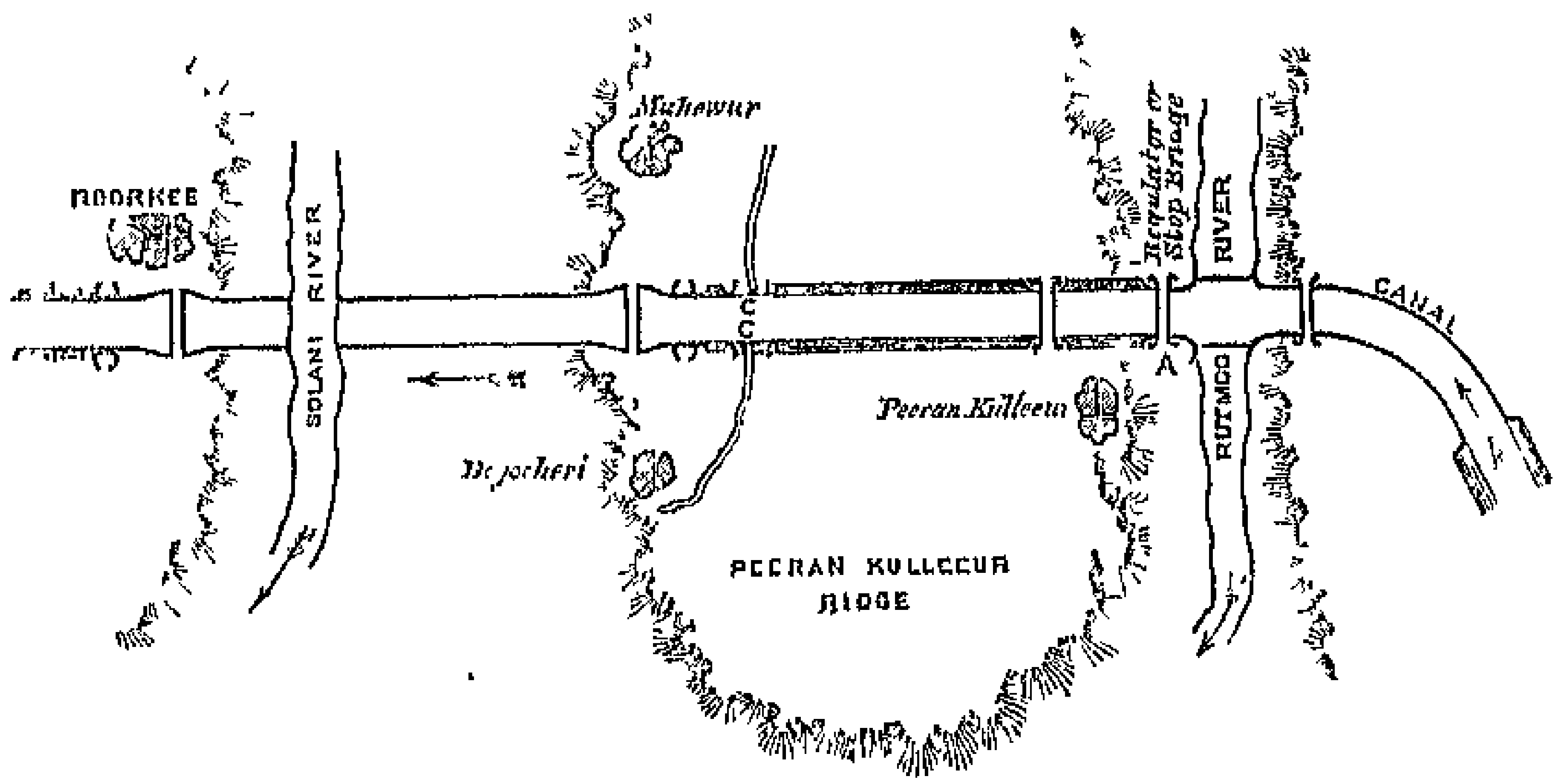


Here A B represents the canal channel intersecting the Burrumpoor nulla at C; *a b* shows the cut that has been made to remedy the interference with the drainage caused by the canal embankments, and to pass the flood-water of the Burrumpoor nulla into the Solani valley west of the village of Muhewur. At the point C, the escapes which I have alluded to above are situated; they rest, it will be observed, on the end of the aqueduct buildings, with which they are in contact.

The following diagram will show the object of these works, which are merely protected passages, to be made use of on extreme emergency. They are in no way connected with regulating supply, or with the relief from superfluous water under ordinary circumstances; they are, in fact, safety valves, in the event of serious injury

to the line of works in the valley, to be used only as a last resource, when every other remedy fails. It will be understood, moreover, that they are filled in with earth, and, excepting from the protrusion of the flank walls on the canal front, are concealed from sight. They would be brought into operation by working parties, who would remove the earth sufficiently to give a passage to the current.

Diagram 110.



The above diagram, which represents the works connected with the Rutmoo and Solani torrents, will show that, by closing the regulator or stop-bridge at A, and by opening the sluices of the dam lying across the Rutmoo River, the whole of the canal supply is turned off. The canal channel below the regulator is laid dry, and the water passes down the Rutmoo.

The distance between the stop-bridge at A, and the up-stream terminus of the Solani Aqueduct, and the two escapes lying in contact with it at C, is exactly 14,629 feet. The channel on this distance being on a rectangular section of 140 feet in width, with additional side slopes on a depth of 12 feet, equal to $1\frac{1}{2}$ to 1. Supposing that a serious accident was to occur on the

line of aqueduct, which rendered an instantaneous riddance of water necessary, the remedy would lie in closing the stop-bridge at Rutmoo, by which all further access of supply would be stopped. Assuming an extreme case, in which at the time the regulator was closed there was a depth of 10 feet of water in the canal, the quantity of water which it would be necessary to get rid of before the channel at the point C was laid dry would be equal to an amount $14,629' \times 1,500' = 21,943,500$ cubic feet, independently of that standing on the aqueduct channel at the time. It was under this view of the question that I determined on providing the means of relieving the channel from as much of this water as was possible, by making the escapes at C. It is by no means improbable that a more efficient remedy may be invented for getting rid of the earth which now fills these escapes than that which I propose; the permanent establishment of labourers which will be maintained for the repair, clearance, and maintenance of the embankments and their slopes, will always, however, be at hand; and as the cutting of embankments on emergency is not an uncommon expedient in dangerous floods, it is possible that the present arrangement will answer. I have an objection to permanent works for regulating the supply being built either near the aqueduct, or at this particular spot. Such works, when built on a country like that of the Khadir, lead to marsh and quicksand, and would introduce rank vegetation on the tail line of escape. They would be particularly open to objection from this circumstance alone, as regards the health of the neighbouring country; but the proximity of the means of *regulating* supply offered by the Rutmoo, renders further works, intended for this purpose merely, quite unnecessary. The escapes at C are either useful on emergency, or they ought not to have been built at all. I have, after mature deliberation, built

them; they at least offer an alternative which, without them, would not exist.

From what has been said before, it will be understood that the embankments are carried over the escapes above described, so that the slopes of the canal channel impinge upon the terminal works of the aqueduct.

The termini consist of a circular quay or bastion, 30 feet in diameter, raised to a height of 12 feet, or to that of the berm or towing-path. This form of structure admits of the junction of the earthen channel with that of the masonry under more convenient circumstances than any other shape; and in the present case, the extent of diameter, when compared with that of the slopes and berms of the earthen channel, affords a security against the effects of the current. These bastions are surmounted by pedestals, bearing upon them effigies of the existing African lion, recumbent, with their heads erect, and looking outwards from the aqueduct, or up-stream on the upper, and down stream on the lower terminus.

To the bastions on the aqueduct side a line of ghats or flights of steps from the berm level to the water is carried for a distance of 75 feet, until it meets the cattle ghats. These ghats are inclined planes, extending from the rear of the embankments to the water, for the purpose of giving access to cattle for drinking purposes. This inclined plane, which is 50 feet in width, is crossed by five flat masonry arches of 17 feet in span, so as to keep up the line of communication along the berm. Each flank of the cattle ghat is protected by a wall terminated by an octagon tower, or, as has been described in the chapter under the head of Bridges, by what the natives term a *bytuk*, or place for sitting upon. From the cattle ghats, flights of steps, like those that are in contact with the terminal bastions, approach the bridge in the form of

an ogee gradually expanding from a width of 150 to 179 feet. These steps come in direct contact with the face of the bridge, which consists of three arches of 55 feet span each, with piers of 7 feet; it comes under class No. 1 of the bridges described in a former chapter. The bridge roadway being elevated to a height of 24 feet, whilst that of the berm is only 12 feet; the former is gained by a ramp with a slope of 3·668 in a hundred. The ramp towards the berm is covered by a retaining wall, which terminates at the foot of the slope, and at the commencement of the ogee. The bridge roadway, which is horizontal, has a width between the plinths of the parapets equal to 17½ feet, and the approaches from the country are on a slope of two in a hundred.

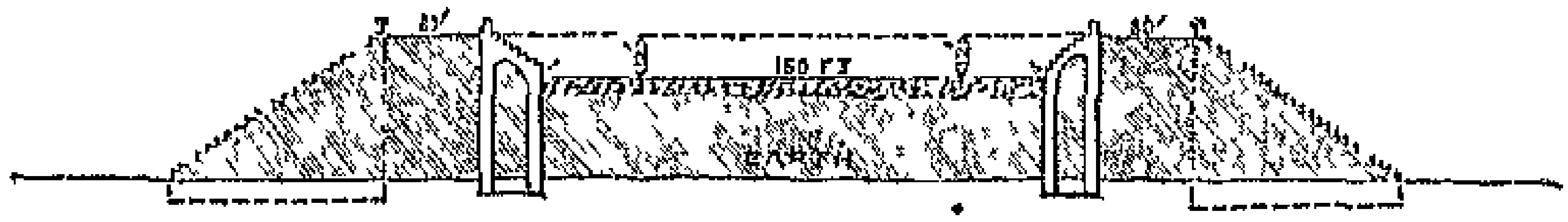
The terminal works, including the bridge, and measuring from the extremities, are 571 feet in length. The detail is the same on both the up and down stream termini. The bridges, the former at Muhewur, and the latter at Roorkee, are in every respect, as far as superstructure is concerned, identical.

From the bridges that constitute the lines of terminal communication, the earthen aqueduct across the valley may be said to commence. The revetments, which are on precisely the same scale and shape as those before described, leave the bridge in a corresponding ogee, and proceed onwards in direct parallel lines, until they come in contact with the aqueduct proper, or masonry work, under which the torrent of the Solani River is carried. To meet this work, the extreme width of which between its flanks is 172 feet, these revetments again expand into ogee curves, the extent of expansion being from 150 to 172 feet.

The total length of the revetted channel on the up-stream side is 10,713 feet. On its down-stream it is

2,723 feet. The transverse section is shown in the following diagram :—

Diagram 141.



The design of the revetments as originally planned and figured in my report of 1845, was (in consequence of my anticipation of the discovery of kunkur in great abundance in the neighbourhood not having been realized, and from a necessity therefore of reducing the amount of masonry) considerably modified both in principle and construction. Although, comparatively speaking, only a small portion had been done previously to my rejoining the works in 1848, the reasons for making the alteration appeared to me sufficient to prevent my returning to the old model. By showing in diagram, sections of the revetments as originally designed, as modified, and as afterwards improved, this part of the work will be perfectly understood.

Diagram 142.

Fig. 1. Fig. 2. Fig. 3.

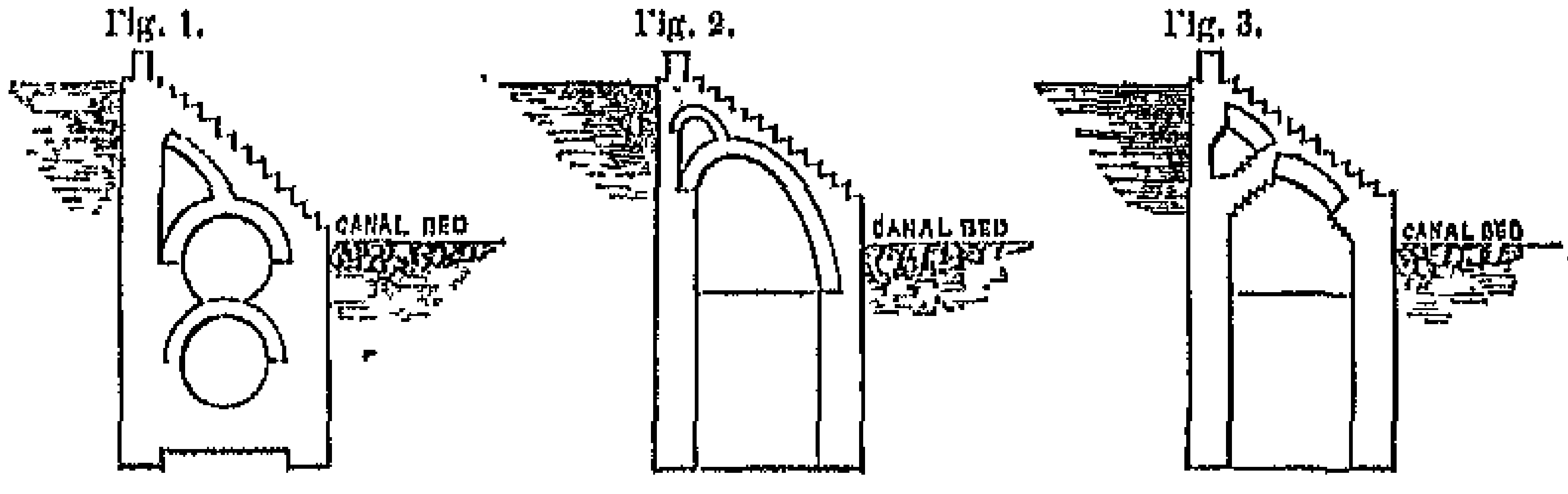


Fig. 1.—Shows the original design, the principle of which was that the revetment should, as far as stability was concerned, be entirely independent of the pressure of the earth, either from the embankments on the outside, or from the canal on the inside. The carrying out of this design, however, depended on the resources in kunkur and brick; its cubic content was considerable.

Fig. 2.—Modified design. The front and rear walls were tied together by a transom or cross-wall at every 15 feet, this cross-wall extending to a height of feet.* In this section the decrease of masonry over that in Fig. 1 was very great. Its stability, however, depended on the earthwork, and on the contingencies of thrust, arising from the earth both on the canal and embankment sides. Consequences arising from this, which occurred during the rains of 1848, led me to modify the section by attempting to obtain a more satisfactory *equilibrium of the parts*, than it had at that time. It was difficult to do this without falling back into the evil of increasing the cubic content, an evil which the above design had got rid of.

Fig. 3.—Shows the remedy that was applied in the above case: it increases the cubic content, but decreases the amount of arch-work; and in principle it relieves the back wall from a portion of the thrust that exists in Fig. 2, by throwing the weight more forward, and by dividing the action, both of weight and thrust, more equally throughout the mass.

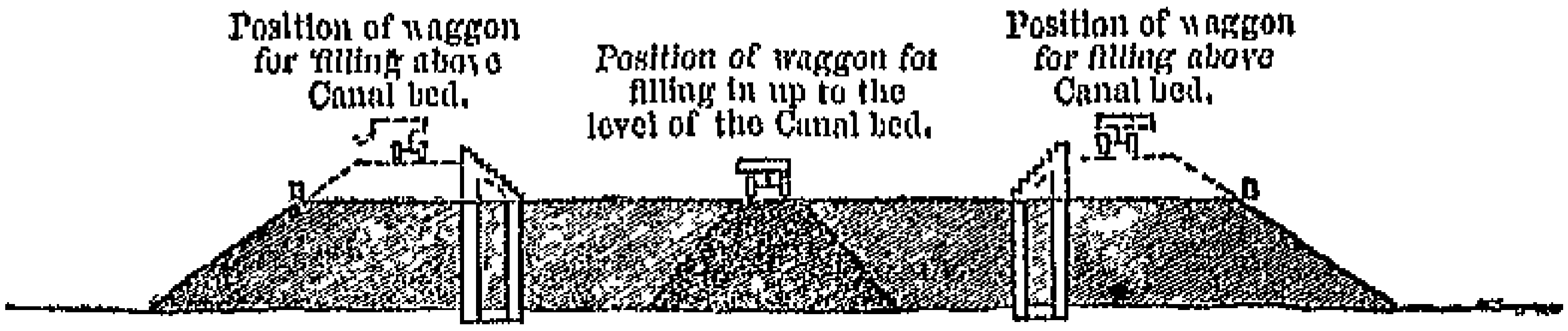
* The height varies with that of the revetment, the cross-wall being in all cases carried up to the height of springing of the arch of Fig. 2.

With exception to those portions of this revetment which were built previously to the year 1849, the whole have been constructed on the design figured in the third section. They have been built almost entirely of brick, the exceptions being on the Muhowur side, where kunkur, as far as that material could be procured, was used; and on the Roorkee side, where a considerable portion of the walls has been built of vitrified masses from the kilns. These vitrified masses (nat. *jhama*) have been used in masonry whenever they were available, although they have chiefly been turned to account in the ballasting of the railways.

In addition to the revetments which face the embankments on the sides of the channel, the exterior slopes are, at each 1,000 feet of their length, accommodated with flights of steps, 4 feet in width, for the purpose of facilitating the communication between the high and low levels. The height of these flights of steps varies with the distance from the side of the valley. Those which are in the closest approximation to the aqueduct proper, or to the channel of the Solani River, are, from the terreplein to the top of the embankment, 31½ feet. This, in fact, conveys an idea of the variety of heights to which the section figured in diagram 141 is subject. From the terminal bridges, where the surface of the earth and top of embankment are on one level, the height or depth of revetment gradually increases, until its arrival at the aqueduct proper. On the Muhowur side it is equal to 37¼ feet, and on the Roorkee side to 36¾ feet. The exterior slope steps which I have above alluded to, are confined entirely to the Muhowur line of embankments; that on the Roorkee side being provided on the left with conveniences of the same description at the extreme ends which are in contact with the aqueduct proper and the workshops. On the right, with steps at the aqueduct end only.

Reverting to diagram 141, which represents a section of the revetted aqueduct in its completed form, the progress of construction will be understood from the following diagram :—

Diagram 143.



The deep shade in the centre of the canal bed represents the embankment, which was pushed forward from Roorkee and Muhewur to support the railroad. In correspondence with the advance of this road, earth was brought for filling in to the right and left, or up to the level of B B. This was done in the method described below; its progress was continued through a period of five years; and its object was to obtain, by a succession of rainy seasons passing over it, the utmost extent of consolidation to the earthwork.

Diagram 144.

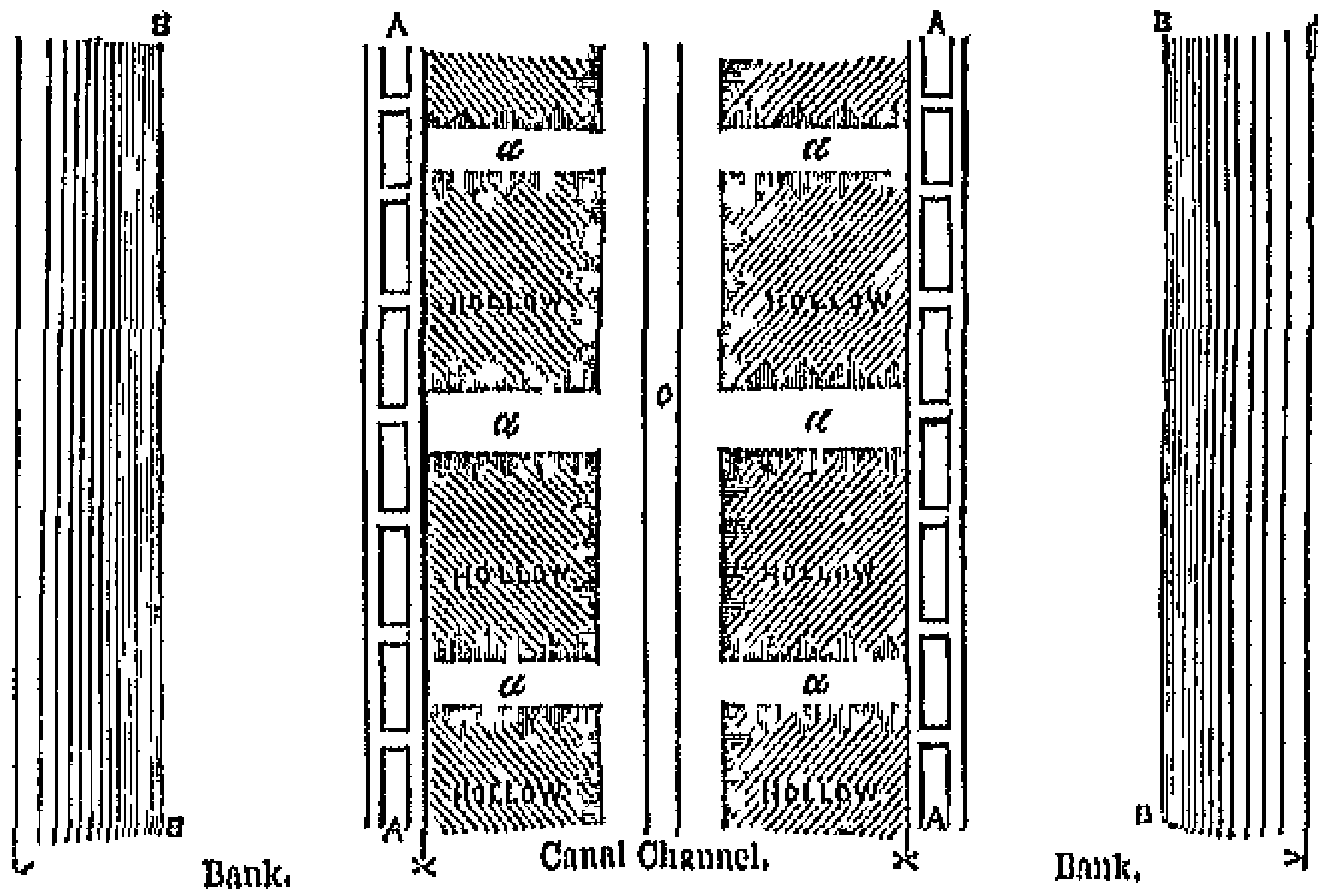


Diagram 144 exhibits a ground plan of the revetments A A A A, on either side of the centrical line of

railroad *c*, the lateral flanks, *a a a a*, being roads raised to a level with the railroad, for the purpose of carrying the earth to the embankments in rear of the revetments, or as far back as the lines B B B B. The spaces between the lateral roads *a a a a*, which left the line of rail at every 200 feet, and which are shown in the diagram by shade, were left hollow, so as to act as reservoirs for receiving water during the rains. They acted as ponds for the purpose of distributing moisture by absorption, and by these means of gaining consolidation by actual settlement. During the whole of the period when this was going on, the embankments in rear of the revetments, as well as the spaces in the revetments themselves, were in progress up to the level of B B, diagram 143. Early during the season of 1852, and as the works became more advanced, the ponds or reservoirs above described were filled in, and work was commenced on the section above the level of B B, as shown by the dots. The plan adopted here was a mere repetition of what had been done in the canal channel on the lower levels, that is to say, lines of rails on both banks were started from Muhewur on the higher levels; and earth from the Peeran Kulleeur ridge was brought forward to complete the work. At this period of our operations, a good deal of earth was obtained for completing the banks and their slopes, by excavations from the outer limit of the side cuttings, as shown in diagram 136, where the triangle *a b c* was removed, and the earth excavated therefrom was thrown upon the embankments. By this plan, we not only obtained earth at a comparatively cheap rate, but we equalized the surface of the ground, which in the neighbourhood of the side cuttings had, by weathering and by the action of rain-water, become very irregular. On the Roorkee side, local circumstances prevented an arrangement of this sort. In that case, the earth was

carried from the rail by inclined planes towards the higher levels, and the whole of the embankments were completed without the aid of additional railroads. I may observe that, even on the Muhewur side, inclined planes of the sort used near Roorkee were practised with great advantage in expediting the completion of the rear embankments. Here, however, this was the exception; on the Roorkee side it was the general rule. The accidents that took place during the progress of this work were limited entirely to slight disarrangements of the revetments. These happened during the rains, either by collected water passing round unfinished portions of walls, or, as in the case of fig. 2, diagram 142, by the rear wall being acted upon by the thrust of the arch. In those cases, an irregular disposition of earth led to disarrangement, but nothing of a serious character occurred. I believe that, with the exception of the results of a heavy fall of rain that occurred in 1850 (when a number of the lateral roads *a a a*, figured in diagram 144, failed, by which the collected water from a succession of reservoirs forced its way along a line of revetment, and knocked down the unfinished end of it), all the disarrangements, slight as they are, which have taken place, have arisen entirely from unequal distribution of the earth in connection with the walls. In cases where the revetment has been enveloped both inside and out with earth equally distributed, the walls have not suffered in the slightest degree.

The way in which the earth was carried, the species of draught used, and the rates per 1,000 cubic feet of work executed in the earthen embankments, became a very interesting part of the history of the aqueduct. It will be recollected that in the early stages wheelbarrows and daily basket labour were the means by which a good deal of the main body of the embankment was formed.

The introduction of railroads and waggons relieved us from wheelbarrows and baskets, but for a long time kept us with men both for excavation and for propelling the waggons. As time advanced, horses in some measure took the place of men; and on the 22nd December, 1851, we started a locomotive, which I believe to have been the first engine of the sort that was ever used in India. We therefore went through all the grades of carriage, with varied results, all of which, however, appeared to be dependent on local causes, or economical arrangements with regard to time. Our methods of working, therefore, were—.

1st. With baskets and wheelbarrows.			
2nd. With earth-waggons propelled by men.			
3rd. With	do.	do.	by horses.
4th. With	do.	do.	by locomotive.

With regard to the first, it is unnecessary to lay any particular stress, further than that it led to the introduction of a very efficient species of barrow, which is figured in Plate XXVII. of the Atlas. In using this barrow, a leather shoulder-strap was distributed for the purpose of giving relief to the muscles of the arm; an introduction which was adopted with unlooked-for celerity by the labourers themselves, who now consider the strap as a necessary part of the wheelbarrow. This circumstance, trifling as it may appear, is so far a matter of interest, that it shows how ready the native of India is to renounce old habits, and adopt new inventions, if he practically comprehends a reason for doing so. The wheelbarrow, after all, however, is entirely European, and is so little understood by the native of India, that instances have been known of their having been served out to excavators, and used by them as baskets, *i.e.* filling them with earth and carrying them bodily on their heads!

The second item, where the earth-waggon is pro-

pelled by men, was for a long while the only method used on these works. It has, even up to the last, been largely practised, and taking the extraordinary cheapness of human labour into account, it may, after all, be the cheapest. In estimating the value of labour, however, in a large work like that of the aqueduct, we must look to time, as well as to facilities for procuring labourers. The use of cattle supplies the place of men, when such are either to be procured with difficulty, or when they may be more economically employed elsewhere; and in this respect they possess a value independent entirely of the actual cost of their employment.

I have before stated that the waggon in use on these works is of a side-tilt pattern. It carries from 45 to 50 cubic feet of earth, or from 30 to 33 cwt. When men were used in propelling these waggons, 4 beldars or excavators were told off to each, one man remaining at his post digging and loosening the earth ready for loading, whilst 3 men were engaged in working the waggon. On the return of the waggon, the whole party dig and aid in refilling it. Filling a waggon by 2 men takes from 50 minutes to one hour, the earth being carried 30 feet on an average. Emptying takes from 10 to 15 minutes. These 10 or 15 minutes include all the time from the arrival of the first waggon at the spot where the earth is to be deposited, to its leaving it again, by which time the last waggon of the train has also deposited its earth, and commenced its return trip.

In the third item, where the waggon is propelled by horses, each waggon requires 2 beldars for digging, who remain at the excavations whilst the waggon is performing its trip, and who refill it on its return. The horses in this case being in charge of a saees, or groom specifically paid for the purpose. A horse travels at the rate of 2·85 miles per hour with a load, and 3·25 miles

with an empty waggon. Two waggons are drawn by one horse.

Mr. Parker, in estimating the value of waggon labour with men and horses, has, from a series of five months' accounts, in which are included the charges for excavating and carrying 1,317,000 cubic feet of earth, abstracted the following tables. The first when the waggons were pulled by horses, the latter when they were pushed by men:—

TABLE 5.—AVERAGE OF LABOUR required for 1,000 cubic feet of digging, and carrying the earth in waggons drawn by horses, to a mean distance of 9,200 feet, by railway.

Description.	Average Number.	Remarks.
Mates of beldars	0·83	From this table we find that 108 cubic feet is the day's work of a digger, and 352 cubic feet that of a horse.
Diggers	9·23	The diggers have also to carry the earth in barrows a mean distance of 40 feet, in order to fill the waggons.
Horses, effective	2·84	
Ditto, in hospital	0·40	
Ditto, non-effective by Sundays, holidays, and rain	0·70	
Men on scaffolding, and greasing waggons: beldars	0·72	
Do. carpenters	0·08	

TABLE 6.—AVERAGE OF LABOUR required for 1,000 cubic feet of digging, and carrying the earth in waggons pushed by men, to a mean distance of 8,700 feet, by tramway.

Description of Workmen.	Average Number.	Remarks.
Mates of beldars	0·56	From this table we find that 50 cubic feet is the day's work of a man, digging and carrying.
Diggers and carriers	19·70	
Men on scaffolding & greasing: beldars	1·00	
Do. carpenters	0·16	

The cost of digging and carrying 1,000 cubic feet of earth, as in the last table, was rupees 3-13-0, which

includes payment for Sundays, when no work is done. Had Sundays not been included, the cost to Government would have been rupees 3-3-0.

In the same manner, the cost of digging and carrying 1,000 cubic feet earth, as in Table 5, was rupees 3-12-0, detailed as follows, viz.:—

	RS.	A.	P.
Superintending	0	1	10
Digging	1	9	4
Carrying by horses	1	10	2
Greasing and oiling waggons	0	2	2
Scaffolding	0	4	6
Total, Co.'s rs.	3	12	0

which includes payment for Sundays. Had Sundays not been included, the cost would have been rupees 3-2-0.

In the first case it will be observed that the distance to which the earth was carried was 9,200 feet on railway; in the second case, the distance was 8,700 feet on a tramway, or on the flat bar rail before described.

The above gives a fair return of the average, on work done up to the end of April, 1851. The following tables represent the averages of the two following years, or up to the 30th April, 1853, when the use of horses especially had become well matured, and at a time when a comparison between their value and that of men as motive power could be better appreciated. The word "comparison" is, perhaps, not a fair one to use in this case, as the distances to which the waggons have to travel is one of the chief elements in the rates, and these in the latter years have been much in excess to that on which the tables above given have been drawn up. The roads too have been much improved since the early days of progress, and experience and practice have rendered both men and horses more ready and expert in their respective duties.

AVERAGE of LABOUR required for 1,000 cubic feet of digging and carrying earth in waggons drawn by horses, to a mean distance of 11,300 feet.

Description of Labour.	Average Number.
Mates	·62
Diggers	15·65
Men on greasing axles	1·20
Horses, effective	3·95
Ditto, non-effective	·84
Ditto, ditto, in hospital	1·16

64 cubic feet = day's work of a digger; and 258 cubic feet = that of a horse, excluding Sundays.

The cost of the work is as follows:—

	RS.		RS.	
Excavating	2·18	per 1,000 cubic feet, or	·050	per ton,
Carrying	1·43	" "	·032	per mile.*

Cost of excavating is constant, that for carrying varies with the distance. Hence it is 1·43 for 1 mile, 2·86 for 2 miles, and so on.

These averages are obtained from the results of one year's work, viz., from October, 1852, to October, 1853. During this time 122 waggons were daily employed, and the total quantity of earth brought down from Muhewur, and deposited in the aqueduct channel, was 7,185,378 cubic feet, or 321,000 tons.

The lubricating material for the axles was a mixture in equal parts of grease, or tallow, and mustard oil, and the quantity of this required for each cart daily was $4\frac{2}{5}$ chittacks. One cubic foot of earth weighs 100 lbs.

AVERAGE of LABOUR required for 1,000 cubic feet of digging and carrying the earth, in waggons pushed by men, to a mean distance of 2,550 feet by tramway.

Description of Workmen.	Average Number.	Remarks.
Mates	·80	50·30, say 50 cubic feet, as the day's work of a digger and carrier.
Diggers and carriers	19·90	Average cost = 3 rupees per 1,000 cubic feet.
Men on greasing axles	·61	

* Weight of the carts has not been considered.

These averages are obtained from the records of one year's work, leaving out the months of December, May, July, and August, when the men were fined on account of little work.

During this time, nineteen waggons were daily employed, and the total quantity of earth carried by their means to the Rutmoo embankments from Peeran Kulleeur was 1,652,644 cubic feet, or 73,700 tons.

When the excavator does not carry the earth he has dug, it will be observed in the former table, that he does a daily task of 64 cubic feet. This reduces itself to 50 feet when he has also to carry the earth, as in the latter table; so that $\frac{50}{64}$ and $\frac{14}{64}$ will represent the labour done respectively in digging and carrying. In the present case, where the two operations are combined, rupees 2·34 and rupee ·66 will be what is due to each. first always remaining constant, the latter varying with the distance, and increasing to rupee 1·36 when the distance becomes a mile.

$$\left.\begin{array}{l}\text{Hence, } 2\cdot34+1\cdot36=3\cdot70 \text{ rupees, cost for 1 mile} \\ \qquad\quad 2\cdot34+2\cdot72=5\cdot06 \quad ,, \qquad ,, \quad \text{2 miles}\end{array}\right\} \text{per 1,000 cubic ft.;}$$

and so on.

On the fourth item our experience in rates of earth as obtained by the use of a locomotive, was too short to admit of our arriving at any satisfactory conclusions, an accident having placed the machine *hors de combat* a few months after it had been on the works. Lieutenant Allen, whose establishment had charge of the locomotive, attributed no blame to the parties concerned. The water had been drawn off, and it was supposed that the fire had been entirely extinguished. A storm with wind, however, brought the fire and fuel which were in the furnace into action, destroyed the casing, together with a number of the tubes, and placed the locomotive completely out of use.

This misfortune, although it put a stop to the use of a power which I had anticipated as one that would be of great service to us, and in some degree make us independent of beldars or diggers, may not be considered altogether as the cause of the locomotive having been discontinued. Valuable as it was as an adjunct to the motive power which we already possessed, it had the inconvenience of occupying an entire line of railway, to the prevention of its use by the numberless waggons that were required, not only for earthwork, but for the carriage of materials. We had not a sufficiency of rail to provide separate accommodation for it, nor had we leisure (as time was a great object) to make sacrifices for the purpose of keeping the engine at work. Labourers appeared to be in sufficient abundance, and the horses, which at this period were very generally employed, gave steady occupation to the waggons, which the constant interruption arising from repair to the locomotive prevented in a very serious degree. This evil might, perhaps, have been remedied, had we, instead of having only one, had three or four locomotives, by which a perfect might have been substituted for an imperfect machine. The locomotive that we had was placed in the hands of a practical engineer, Mr. Murdoch, who (although he had never been actually employed as a driver or stoker on railroads) had all his life been connected with steam machinery. The engine was in some way or other imperfect in the adjustment of its parts; it was continually getting out of order, and appeared to be another specimen of "machinery for exportation to the colonies."

The locomotive is small and compact; engine and tender in one frame; adapted from its water and fuel arrangements to moderate distances only, and applicable to draw on a level line of rail a train of ballast waggons of

an aggregate weight of 180 to 200 tons at a speed of four miles an hour. Of the parts most liable to fracture we have duplicates, as well as of the wheels, both driving, tail, and leading. Its name is the "Thomason." The executive engineer in charge of the Northern Division of the works, in writing to me on the subject of its applicability for the particular duties which the aqueduct works required from it, remarked: "The locomotive started first on the 22nd December, 1851, at the Roorkee end of the railway; my intention being to teach natives to drive at that end, as being more convenient to Mr. Murdoch, whose other duties required his presence in the workshops. Moreover, the employment of the locomotive on the Muhewur channel line would have thrown a large number of horses out of work, and would also have seriously interfered with the general usefulness of that line in respect of carriage of materials. It soon became necessary, however, to repair the light Roorkee line which is laid with flat iron; and what with these repairs constantly repeated, and what with interruptions of other sorts, Mr. Murdoch's attention being much required on the condensing engine and workshop machinery, at first the driving did not progress very fast. After repeated repair, it became evident that the Roorkee line could never be made available for the locomotive, owing to its weakness; and but for the necessity of teaching native drivers whilst the weather was cool, I should have preferred shelving the locomotive for the time being. As it was, directly I was satisfied of the impracticability of working the locomotive on the Roorkee line, the new Muhewur embankment line was pushed on as rapidly as possible, and on the 15th of March last, having a portion of the latter line on which horses could work, although still under some disadvantage, the locomotive was removed over to the other side of the river, and the subjoined

table will show its performances during the remainder of that month :—

Date.	Number of Loads.	Quantity of Earth carried.	Distance.
		Cubic feet.	Running feet.
1852. March 22 . . .	30	18,057	15,000
" 23 . . .	23		
" 24 . . .	. .		
" 25 . . .	20		
" 26 . . .	. .		
" 27 . . .	. .		
" 28 . . .	. .		
" 29 . . .	75		
" 30 . . .	89		
" 31 . . .	90		

Captain Goodwyn continues: "That nothing but the necessity of teaching natives to drive during the cold season, and shame at seeing the locomotive standing idle, has induced me to allow it a place on the Muhewur channel line. I have done it in spite of my better judgment; and now the running of the engine is getting into order, I do not like to break up the arrangements, although, until the Muhowur embankment railway is run out much further, we are, I consider, using the locomotive at an extravagant loss."

"The want of progress of the Muhowur embankment *railway has been caused indirectly by the sickness of the* officer in charge. I have done my utmost to push it forward since the middle of February. During the month of April, the work of the locomotive has shown a considerable improvement, and once the engine has brought 114 loads during a day. Advantage was taken of the presence of the only well-trained driver being required at the Roorkee workshops to attend the condensing engine *for a few days, to take up the only portion of the line* traversed by the locomotive laid with flat iron, substi-

tuting in its place English rails. During this operation, the working of the locomotive was stopped, and hence its progress report for April will show rather poorly."

Date.	Number of days working	Number of loads drawn.	Quantity of earth carried.	Distance.
			Cubic feet.	Running feet.
April, 1852 .	10	687	34,350	14,000

During the ten days included in the above table, $16\frac{1}{2}$ trips were made by the locomotive; giving an average of $41\frac{1}{2}$ loads per trip, or 68·7 loads per diem.

At a rate of about 10 miles an hour, the engine with an accommodation carriage and string of ten loaded waggons passed over the rails very easily and quietly. The difference between the motion when passing over the English rail and the iron bar being, as I before remarked, very remarkable, the former being as superior to the latter, as a kunkur metalled road is to a common district one. Mr. Murdoch on this occasion, as he had on former ones, adverted to the absence of coke, and the use of wood and charcoal as a great loss to our steam furnaces. He informed me that even in the short distance upon which the locomotive ran, which at that time did not exceed $2\frac{1}{2}$ miles, he was forced to carry an extra waggon for tender purposes.

As an aid to our operations in constructing the aqueduct, the locomotive has been a failure, not from its want of value as a motive power, but from its inapplicability to the local circumstances under which the work was carried on. The extract above given from the executive engineer's report shows very clearly the difficulties under which he laboured.

The engine attached to the locomotive was in its

original design so contrived as to be adapted to use as a fixed one in the workshops. In so far, therefore, our want of success on the road has been met by the introduction of by no means an useless addition to our workshop steam power, whilst at the same time the engine is available for its purposes as a locomotive at any future time when it may be wanted. I fully anticipate that such will be the case on the railroads that will ultimately be established on each of the aqueduct embankments, extending from Roorkee to the Rutmoo; here the immediate despatch of stores of materials, or in the case of earthwork repairs, the rapid collection of material for the purpose, will be very satisfactorily met by the presence of a machine of this description.

From the above it will be seen that to men and horses we have been indebted entirely for the progress made in the execution of the earthen aqueduct. This progress has been from early in 1848, up to the 8th April, 1854, in a state of steady advancement, and both our men and our material are in a high state of efficiency.

The two following tables will give an idea of the rates of earthwork as executed. They are those charged by the executive engineer in his quarterly bills, and include all contingent expenses, dependent on the repairs and maintenance of the plant. The first shows the cost where men are used as propellers to the waggons, the latter, where horses pull them.

Rates of Earthwork as executed on the Solani Earthen Aqueduct in ballast-waggons propelled by men.

Distance.	Rate per 1,000 cubic feet.						Remarks.
	Including spreading.			Not spread.			
Running feet	RS.	A.	P.	RS	A.	P.	
447	4	7	9	..		..	Rammed.
1,500	4	9	10	..		..	
1,500	4	15	4	..		..	
2,000	5	2	4	..		..	Rammed and watered.
2,000	3	2	3	..		..	
2,200	5	3	8	..		..	Carried to vaults and puddled.
2,760	3	9	6	..		..	
3,070	3	12	2	..		..	
3,240	2	15	5	..		..	
3,350	..		..	2	8	4	
3,387	3	10	2	..		..	
3,483	3	4	10	..		..	
3,918	6	6	11	..		..	Carried to vaults and rammed and watered.
4,000	2	4	9	..		..	
"	3	2	8	..		..	
"	3	3	8	..		..	
"	3	4	1	..		..	
"	3	4	9	..		..	
"	3	8	8	..		..	
"	3	9	10	..		..	
4,029	3	13	8	..		..	
4,030	3	15	2	..		..	
4,125	3	14	4	..		..	
4,150	3	6	8	..		..	
4,200	4	1	6	..		..	
"	4	2	4	..		..	
"	..		..	2	12	5	
"	..		..	2	13	4	
4,433	3	7	4	..		..	
4,440	3	14	2	..		..	
4,720	..		..	2	14	7	
4,766	3	11	8	..		..	
4,947	3	14	2	..		..	
5,000	..		..	2	13	10	
5,200	..		..	3	14	1	
"	..		..	3	15	7	
5,350	..		..	3	7	1	
5,366	4	2	5	..		..	
5,400	3	8	9	..		..	
5,407	..		..	3	14	1	

Distance.	Rate per 1,000 cubic feet. Including spreading.			Not spread.			Remarks.
Running feet.	RS.	A.	P.	RS.	A.	P.	
6,594	4	8	11	..		..	
6,800	4	1	8	..		..	
7,000	3	11	10	..		..	
7,215	..		..	3	11	3	
7,672	..		..	3	5	0	
7,702	..		..	3	5	2	
7,783	4	7	6	..		..	
8,000	..		..	3	2	6	
"	..		..	3	13	10	
"	..		..	3	14	8	
"	..		..	4	4	1	
8,180	..		..	3	11	3	
8,230	..		..	3	8	2	
8,446	..		..	3	8	2	
8,456	3	4	10	..		..	
8,500	..		..	4	4	4	
8,843	4	10	7	..		..	
9,000	..		..	7	9	0	
9,030	6	4	1	..		..	
9,186	5	13	1	..		..	
9,365	5	3	11	..		..	
11,200	..		..	4	0	5	

Rates of Earthwork as executed on the Solani Earthen Aqueduct in ballast-waggons drawn by horses.

Distance.	Rate per 1,000 cubic feet, exclusive of spreading.			Distance.	Rate per 1,000 cubic feet, exclusive of spreading.		
Running feet.	RS.	A.	P.	Running feet.	RS.	A.	P.
7,000	3	4	6	10,763	3	9	1
7,500	3	4	10	11,200	5	0	5
8,673	3	8	10	"	5	15	5
8,540	3	13	2	11,540	5	2	0
8,840	4	15	8	11,555	5	3	2
8,960	5	7	10	12,000	5	12	9
9,400	5	9	10	12,205	5	4	3
9,650	5	4	9	12,400	5	2	0
10,175	4	12	2	14,430	3	13	4*
10,760	5	0	8	15,000	4	3	2*

* It is remarked of these rates that they were too good to last.

The sectional form of that portion of the aqueduct which we are now describing is shown in diagram 141, representing the work as it will be on the completion of the boulder bed, to be extended over the whole of the earthen channel, as a protection against the wear and tear of the current. The depth of this layer of boulders (or round stones from the Ganges River and its neighbouring branches,) will be two feet. The stone ought to be of the largest description procurable, as its value for the purpose intended will depend in a great measure on its immobility. To relieve the works from such a heavy cost, as the transport of so much material by land carriage would entail upon the estimates, this portion of the undertaking has been reserved until after the admission of water into the canal, when the facilities offered by water-carriage will render this part of our operations comparatively simple. For this purpose a number of iron boats have been built ready to be put on service immediately the time for floating them arrives. These with the boats which have been used for a considerable period on the navigable canal for the same purpose, in bringing stones from the Ganges to the Ranipoor works, will give a very good fleet to begin with. I would recommend, however, that the manufacture of either the same class of boat now used, or of a better sort, if such is thought necessary, should be continued, until there is a sufficient number to provide bridges at the different navigable heads, as well as for the transport of stone. For these purposes at least 200 boats might be completed with very great advantage. At the present stage of the earthen aqueduct, the canal bed is raised above the true level, so as to admit of settlement and consolidation; the delay in depositing the stratum of stone will be so far advantageous that it will give time for this consolidation. Taking a practical view of the method to be adopted in

laying down the stone, I would recommend that it should first of all be completed in the immediate vicinity of the aqueduct proper, or in those regions where the bed is the most elevated, and where the side revetments are necessarily the least protected. After this was finished a width of 40 feet, or thereabouts, laid in on the *sides* of the channel nearest to the revetment walls on the whole length of the earthen aqueduct would be the most desirable position for the stone. The central part of the channel would be the last in sequence of this most necessary part of the operations. A good deal of settlement and probably of an irregular nature may be anticipated on such a long line of artificially raised earth. A careful watching of progress in this point will naturally be the earliest consideration, and it is my opinion that many years will elapse before we can hope for the establishment of a bed sufficiently permanent to admit of the full supply. Nor can this permanent bed be hoped for, until the stratum of stone has been laid over the whole of the surface. It is in vain to expect immediate results in the early delivery of large masses of water upon the high land of the Doab at Roorkee, until the works in the Khadir, especially those appertaining to the Solani Valley, are fairly established. The delay that I anticipate is from the bed of the earthen aqueduct merely. The effects upon this part of the work will be the measure by which we can regulate the admission of supply. The constant necessity for laying this work dry, and the importance of doing so for the purpose of watching the action of the current, are matters upon which its ultimate security, and in fact its early efficiency as a permanent line for the carriage of a body of water depends. No feelings of disappointment, nor of desire for rapidly gaining results, ought to militate against the views which I have here recorded. The works are of a nature

unknown in any of the canals yet constructed in these provinces. I believe that the difficulties which we have had to contend with, in the impracticability of disposing of the mountain torrents otherwise than by maintaining them on their natural courses, will be hereafter (even when canals are taken from all the great rivers that debouch from the Himalayas), as they now are, a remarkable feature of the Ganges Canal works. At any rate the peculiar nature of these works demands peculiar treatment; and it can only be by slow and deliberate management that they can be expected to answer the purpose for which they were designed.

It remains now for me to say a few words, in closing this section, on the masonry works which are attached to the earthen portion of the Solani Aqueduct. I have described their design, and for further explanation on this point refer to Plate XXVII. of the atlas, where drawings are given in detail. The terminating bastions, or the circular masses of masonry which come in contact with the canal channel on its approach to, and departure from, the aqueduct, owe their decorative character to the figures of lions on the pedestals. These lions were designed and executed by Lieutenant George Price, of the 1st Bengal Fusiliers, the Assistant Engineer, under whom the aqueduct proper was constructed. The figures, although neither of bronze nor stone, but of plain brickwork, have the merit of being made from the material on which our resources have depended. In this respect they are, in my view of the case, more satisfactory than had they been of a higher order of art imported from Europe. They are specimens of the work of our own engineers, and as such, are alone deserving of credit. The masonry of which they are built, both as regards brick, lime, and workmanship, is of a very superior description. They are stuccoed, and as I have before remarked, they are well

elevated on their pedestals, and look outwards from the aqueduct.

The bridges are, as I have before noted, on the design described as Class No. 1 in the chapter on bridges. They are plain, with their cutwaters surmounted by niched pilasters. The waterway consists of three bays with elliptical arches of 55 feet span each. For a distance of 350 feet on their up and down-stream faces, or on that portion of the revetted aqueduct which is described on ogee curves, the steps or ghats are cut off from the towing-path. This passes round on a ramp made especially for its convenience. The privacy of the ghats is designed for the accommodation of bathers, who can here perform their ablutions without interference from the towing-path. The line of ogee on each flank is in fact a *cul de sac* terminating on the face of the bridge, near which are steps for convenience of passage between the high and low levels.

The cattle ghats which lie between the lions and the ogee curves of approach to the bridge, are works which will be duly appreciated by the village community in the accommodation that they offer to their cattle; in addition to this, at low water they might offer convenient points for the loading or unloading of rafts for which the inclined planes upon which they are built are well adapted. I have before observed that the line of communication along the berm is maintained across these cattle ghats by arches, which render the whole an unbroken and continued line.

The revetments were laid in to a depth of 12 inches below the natural surface of the valley; they were either filled with earth consecutively with the progress of building, or the earth was thrown in afterwards. Upon this earth, which acted as a centering, the arches were constructed, so that the whole mass is formed of well-consolidated earth, protected on the sides of the channel by masonry.

It was a question whether to leave the revetment hollow, or to fill it with earth. The reasons which decided me on the latter course were: 1st, That taking the *proportions of fig. 2, diagram 162, it appeared to me doubtful* whether the walls were *sufficient for stability* without the interior support of earth, especially when the height of the revetments was at its maximum. In this doubt I took into consideration the possibility, if not certainty, of the interior being filled with water, as well as the chances of the action of the current laying the channel front bare to a considerable depth. Secondly, the mere *hollow* shell *offered by the revetment figured* above, appeared to me to be an insufficient protection to the embankments, and with other evils, to give facilities for leakage. On the other hand, well-rammed clay in the interior would add to the water-tightness of the channel in its elevated position above the valley. Thirdly, the construction of the arches and building in general would be greatly simplified by the interior being filled with earth. The *only objection to filling the* revetment with earth, as far as I could gather, was the effect that absorption of moisture by the earth or clay might have upon the enclosing walls. The advantages in favour of solid over hollow revetments appeared to me to be sufficient to prevent the objection above specified from influencing me in the selection. The value of these revetments depends so much upon the efficient maintenance *of the canal bed, that in giving* all our attention to protecting the latter, and in strengthening it by all the means in our power, we in fact do the same service to the revetments.

I have before remarked that with the exception of kunkur and vitrified brick, which, comparatively speaking, have been very sparingly used, the whole of the revet-

ment and terminal works are built with brick masonry, with a lime cement mixed in the following proportions:—

1 part of stone lime,
1 part of soorkee,
1 part of sand.

The brick has been denominated second class, from the circumstance of the best having been selected for the aqueduct proper, for the bridge arches, and for other portions of the work where the hardest material was required. Although bearing the name of the second class, and not so well burnt as the other, it is not to be understood that the brick was of a bad quality. The material was sound, and well burned, and would have been received as such on any large Board of Works. These bricks, in fact, were very much better than those used for building purposes in England, and, as far as I observed, equal to any that I saw on the continent of Europe.

The whole of the outer surface has been stuccoed with a cement of the following proportions:—

1st coat { $1\frac{1}{2}$ part of stone lime, 1 part of soorkee.
2nd coat { 2 parts of stone lime, 1 part of soorkee.

I have in Plate XXVII. Atlas, sheet No. 14, given representations of the kunkur and vitrified brick building as executed. The former, when not laid in blocks, was used as beton enclosed in brickwork strengthened by brick bond. The latter is in horizontal courses, alternating with brickwork, the alternating lines being bounded by brickwork introduced vertically at fixed distances.

The above gives as full a detail as appears to be necessary on the earthen aqueduct line, the great extent to which it is carried rendering it the largest, as well as

the most important part of the Ganges Canal works. We now, therefore, proceed to describe the aqueduct proper, or that portion of the works over the Solani River which comes in immediate contact with the torrent, for the passage of which provision has been made below the levels of the canal bed.

II.—MASONRY AQUEDUCT CONNECTED WITH THE SOLANI TORRENT.

On my return from England early in 1848, I found that the block sinking of the foundations had been commenced, that the whole of the blocks of six piers on the right, or Roorkee side, had been completely sunk, and that others were in progress. Referring to Plate XXVII. of the Atlas, at the period that I allude to, the state of this portion of the work was as follows:—

Completely sunk:—Nos.	40, 41, 42, 43, 44, 45, 46, 47, 55, 56, 57, 58, 59, 60, 61, 62, 71, 72, 73, 74, 75, 76, 77, 78, 135, 136, 137, 138, 139, 140, 141, 142, 151, 152, 153, 154, 155, 156, 157, 158, 167, 168, 169, 170, 171, 172, 173, 174.
In progress of sinking:— Nos.	102, 103, 104, 105, 106, 107, 108, 109, 110, 119, 120, 121, 122, 123, 124, 125, 126.

Some subordinate earthwork in the way of cofferdams for the protection of the above abutment, and a cut made on the left of the river, to facilitate the passage of the stream on the down-stream side of the works, and which existed on my arrival under the name of "Strachey's Cut," had also been done. The state of the works on my return was that of full progress in block sinking.

Certain alterations had been made in the arrangement of the blocks, of the abutment and wings. Lines of blocks had been recommended by Major Baker in substitution for the sheet-piling which was proposed for the front and rear aprons; and the cutwaters which had in my design of 1845 been proposed as mere appendages to

the floorings and apron, were recommended to be founded on blocks sunk to an equal depth with the rest of the foundations. The alterations made to the abutment blocks depended on an increase to the thickness of the abutments themselves, which from 15 feet were extended to 21 feet. The evenly sized blocks which were originally designed for the wings had given place to an outer line of large, and an inner line of blocks of a smaller size. The substitution of blocks for piling at the head and tail of the aprons, and giving massive foundations to the cutwaters, were to reduce as far as was possible the effects of percolation and removal of the subsoil from the floorings, as well as to give to the floorings and to the protective arrangements in their front and rear, greater strength and stability than piling offered. The whole of these alterations were carried out as far as they could be.

The superstructure of the aqueduct is unaltered in its general character from that which was originally designed. Additions have been made in connection with the canal bed, both on its up- and down-stream ends; and in detail of construction, slight deviations (all of which will be described in their proper places) have been made, adapted to particular circumstances.

In elevation, the design, architecturally speaking, is the same as it was originally planned in my report of 1839, 1840. The wings have been altered to broken rusticated basements, supporting pedestals; and the pilasters over the cutwaters have been pierced by circular holes which are intended for the ventilation of the spandrils. These, with a form of cutwater somewhat modified from the early drawings, are the only deviations from the design as first contemplated.

The work will be understood by reference to Plate XXVII. of the Atlas, and to the series of plans which

show the works on the Solani Valley. In viewing it from the valley, it consists of fifteen arches of 50 feet span each. The line of arches is terminated by rusticated wings, each of which supports pedestals, on which are lions similar to those placed on the terminal works, although of larger proportions. These lions face inwards, looking towards the Solani River; and guarding the portal by which the torrent passes through the works.

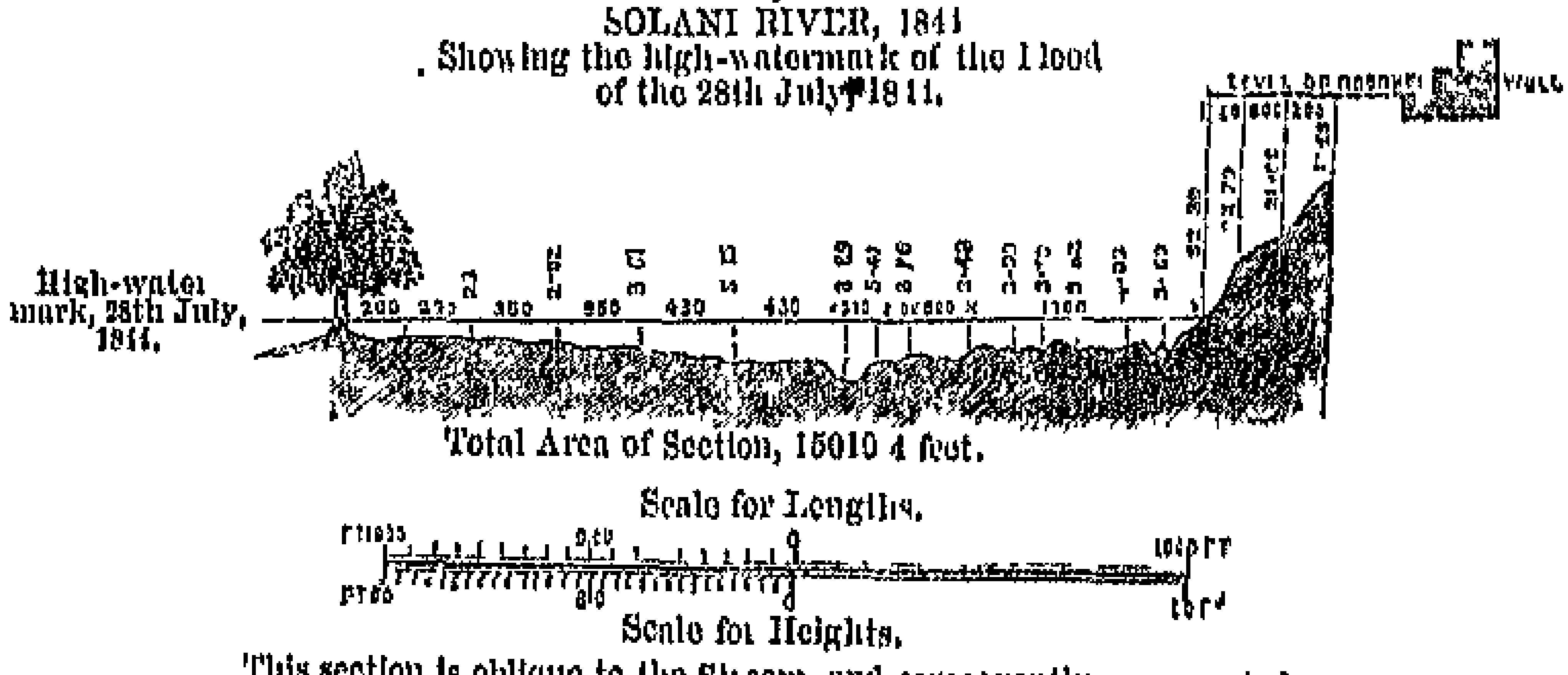
The foundations of this building will be first considered. I have before described the nature of the torrent, the sandy character of its bed, its saturation with springs; and have mentioned, that although during floods, it is the bearer of an enormous quantity of water, at other periods its stream is quite insignificant, varying from 5 to 20 cubic feet per second, whilst in extreme droughts, a superficial run of water ceases altogether. As the dimensions of the foundations are dependent on the amount of waterway of the superstructure, the circumstances by which this was determined may be best explained before I commence upon the details of construction. The original design for the waterway of this river which accompanied my estimates of 1840, gave nine bays or openings of 56 feet each, or an escape in the aggregate equal to 504 feet. This was founded on calculations of floods observed by the natives, verified in some degree by existing marks of high-water. The results were derived from observations hastily taken during the course of a survey, which with its field work, plans, estimates, and report, were all concluded within the space of five months. Further observations, however, appeared to sustain the correctness of these calculations; but in 1844, a flood which occurred during the residence of Captain Turnbull of the Engineers, at Roorkee, although it did not exceed the capabilities of my aqueduct, led to speculations as to the propriety or otherwise of

extending the dimensions of a work, upon the stability of which the canal depended. In submitting my report (with estimates), of 1845, therefore, I went into some detail on this matter; and as the remarks that were then made will be interesting as showing the gradual progress by which the aqueduct reached its present dimensions, I shall here state the views which I then held, promising that up to the floods of 1844, I had determined on so far modifying the former design as to give a clear water-way of 500 feet broken into ten spans of 50 feet each, with a reduction of dimensions to the piers, so as to render the obstruction as small as possible. "In the above estimates I remarked (referring to those of 500 feet waterway) for the passage of the Solani Valley, I have with reference to the probable height of the most extreme floods, projected works, which from the calculated discharge and area of the flood-water of the Solani River, appeared to me to be amply sufficient. There were no indications of floods having reached to a higher level than that shown in the sections above given; and the cultivated state of the tract of low land lying between Bajooheri and Roorkee did not tend to the most remote inference that floods ever occurred of such a magnitude as to lead to their entire inundation.

Diagram 145.

SOLANI RIVER, 1844

Showing the high-watermark of the Flood of the 28th July 1844.



This section is oblique to the Stream, and consequently exaggerated.

The preceding section is that of a flood which occurred

on the 28th July, 1844; the extreme height exceeded by 3 feet that which had been supposed to be the maximum. *By referring to the section of the valley between* Bajooheri and Roorkee, it will be observed that the inundation arising from this flood extends across the whole surface. Its duration at the extreme height did not continue beyond an hour or two in the middle of the day; but at 7 P.M. it was running at a height equal to the highest flood of 1843. I had in my report of 1840 adverted to the circumstance of the country lying at the foot of the Sewaliks being occasionally visited by floods of extraordinary magnitude, and that in projecting the waterway of the Solani Aqueduct, the passage of unusual floods had been *provided for*. This, which was written in 1840, was justified by an experience of twelve years, passed in contending with three of the mountain torrents connected with the Sewaliks, two of which were first-rate. Of the capriciousness of these torrents I had not been an inattentive observer. The periodical occurrence of remarkable floods, confined apparently to the watershed of the Jumna, was exhibited in the rains of 1842. The fall of rain which led to the floods of that year appeared to be confined entirely to the Sewalik Hills and to the forests lying at their base. The mountain streams and rivers connected with them and with the Jumna drainage basin, were charged with a supply of water not known before for many years. The Doab Canal works suffered considerably. The bridges on the high road between Saharunpoor and the Ghurmookteesur Ghat (two of which had remained uninjured since their construction 20 years before) crossing the Dumola, Hindun, West Kalli Nuddi, and other streams tributary to them, were also sufferers in a greater or less degree. Yet during this excessive flood, which affected the country even at the head of the East Kalli Nuddi, the Solani

River did not rise above the extreme high-water-mark noted in the sections that accompanied my plans of 1840. The remarkable fact is, that although the drainage that supplies the Solani is perfectly distinct from that which feeds the rivers above alluded to, the waterheads of each are in contact, and it was natural to infer that the heavy rains that led to the floods of the Jumna slope, were common to the line of hills and forests extending over the heads of the Solani. Local falls of rain, however, *are by no means of unusual occurrence in these regions;* they in fact become one of the many difficulties with which we have to contend in our devices for regulating supply, and frequently lead to catastrophes at one point of the works, when at others no rain has fallen at all. *During the floods of* 1842, *to which I have above* alluded, as causing such destruction to the bridges connected with the rivers under their influence, the high-water on the Ghazioodeenuggur Bridge (a work built over the Hindun, not far from its confluence with the Jumna, although a long way below *the junction of the* Dumola, West Kalli Nuddi, and other tributaries to which it owes its supply) was very much in excess to that of 1844. Here, again, local circumstances affected the magnitude of the floods. In 1842, the bunds which are connected with the Eastern Jumna Canal works, and which are raised to prevent the water of the Muskurra from reaching the works, by throwing its supply into cuts connected with the Hindun, remained uninjured during the rainy season, whereby the whole of the drainage from the Sunsurra and Kalowala Passes flowed down the Hindun. In 1844, on the contrary, the bunds in question broke, and the Hindun was thereby relieved of so much flood water.

I am prepared for the remark that with such an extended section as that shown in diagram 145, a por-

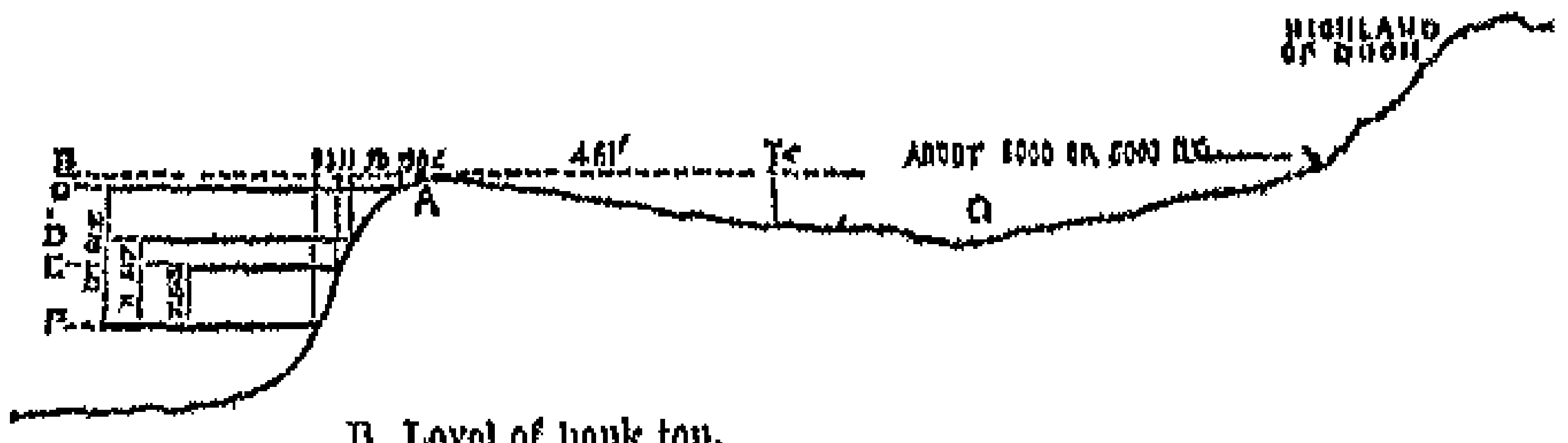
tion of the water would be still or merely inundation. It is difficult to say to what extent this might exist; and the impracticability of measuring the superficial velocity on different portions of the width of a river of this description, so as to obtain an approximation to the mean of the whole section, leaves us entirely dependent on calculations based on the observed slope of the bed of the river. These, although they may be considered accurate when the stream in the channel of a canal or river is compact and of one depth of section, are not to be depended upon in floods rising above the banks, and inundating the neighbouring country. As an exemplification of this we may refer to diagram 145, which merely exhibits the section immediately in the region of the bed of the torrent. Now, calculating this with reference to mean velocity deduced from the slope of the river, we have a discharge per second equal to 84,108·64 cubic feet, a volume of water which is ten times as much as that which flows in the Ganges during the dry months of the year, and half as much as that of the Rhine on the French frontier, which is said to be equal to 168,258 cubic feet per second. It is impossible to consider (when estimating the surface of the country bounded by the waterheads of the Solani above the aqueduct, or in other words, the catchment basin, which throws its water upon the point where the above section was taken) that so much rain could have fallen; and the inference necessarily is that the mean velocity of the water running on the above section could not have corresponded with the slope of the bed of the torrent. I may observe that the section to which I am referring was by some mistake or other taken obliquely to the course of the river, a circumstance which *per se* affects its value. The results of this observation were no doubt of great importance. The floods of 1844 were of extraordinary amount on the Jumna, as

well as on the Ganges watershed. Villages built on ground usually out of the reach of high-water mark were swamped and cattle drowned. Old branches of the Jumna which for years had been dry, and which previously to the floods of 1844, were covered with forest and gigantic Bur and Simmul trees, showing how long they had remained free from the effects of flood or running water, were during this year swept out, and restored to their former state of river beds. From this era, in fact, we date very extraordinary changes to the amount of water thrown down the Boodhee Jumna during the rainy season, and an increase of volume which in preceding years had been comparatively unknown. In concluding the subject of the floods of 1842 and 1844, and in further exemplification of their height in the latter year, I append a series of observations taken by me in the cold weather of 1844–45 on the main Jumna, at Raj Ghat, in the Deyra Doon. The site where the section embracing this series was taken was at the ferry immediately before the river enters the Sewaliks.

Diagram 146.

JUMNA RIVER AT RAJ GHAT MUNDI, DEYRA DOON,

Showing the height of floods in the rains of 1844 in comparison with those of other years.



B Level of bank top.
C *High Flood, 1844.*
D Said to have occurred about 20 years ago.
E *Common rain-floods*
F. Level of Jumna, 6th November, 1844.
G. *The river flooded all this low land.*

N.B.—The floods of 1844 stood over the floor of the huts at A. The old encamping ground near them was swept away, with timber of all sorts, which had been collected and placed on ground considered to be perfectly safe, and out of the reach of floods.

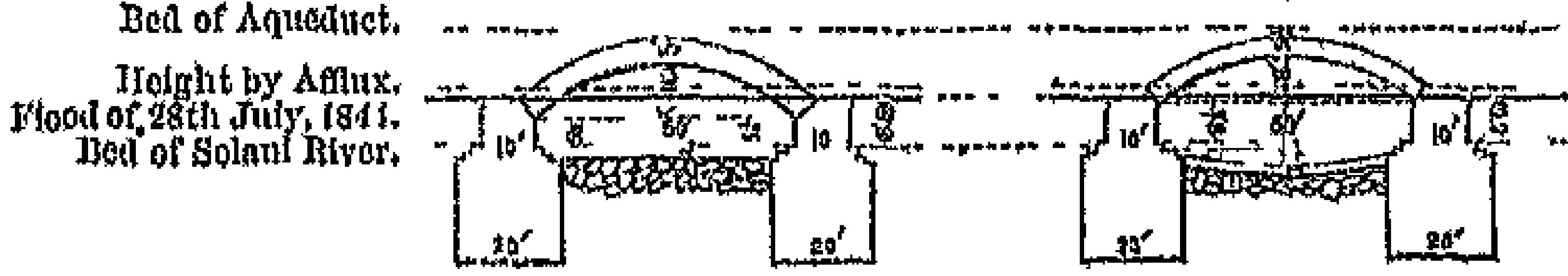
It lies between the junction of the Girree and Asun Rivers with the Jumna, a point that I was well acquainted with, from having annually, for many years, fished in its neighbourhood. My surprise in observing the effects of

the floods at this point was very great. Large tracts of elevated table-land on the edge of the river, which had been always in my recollection used as stacking places for timber, were washed away. The shape of the river was changed; and the Girree, which in former years entered the Jumna at a point on the right immediately above the site where the section was taken, had taken up another position entirely.

In considering the floods both of 1842 and 1844, it became evidently necessary to anticipate the recurrence of similar or even larger ones; and with this view I increased the waterway from ten to fifteen bays of 50 feet each, giving a total width of 750 feet. By adding counter-arches and otherwise strengthening the floorings, and by remodelling the transverse section of the superstructure to meet the increase of headwater, the capacities of opening for the torrent were sufficient for floods of even a greater magnitude than those of 1844.

The improved section at this period will be understood by reference to the following diagram, showing the waterways formerly proposed, and those determined on in 1845. It is interesting to place these sections upon record, that we may compare them with that which was ultimately built:

Diagram 147.



The design of the foundations was adapted to a waterway of fifteen bays of 50 feet each, with piers of 10 feet and abutments of 21 feet in width, the latter being flanked by the wing buildings which were connected to, and continuous with, the revetments and embank-

ments of the earthen aqueduct. The extreme width of the channels for carrying the canal water over the Solani, including their walls or revetments, was 192 feet. The total superficial area that the body of the aqueduct covered was 178,044 square feet, or 982 feet in length, and in breadth 192 feet. Detached from this series of foundations, which were distinctly for the support of the superstructure, there were advanced lines of blocks in substitution of the sheet piling which had been originally proposed, as well as blocks at the terminal points of the piers for the support of the cutwaters. These, with the blocks for the support of the wings and lines of revetment forming the flank approaches to the masonry from the earthen aqueduct, constituted the work to be done in block sinking.

The total number of blocks which are included in the different parts of the work above referred to, amounted to 338, which, for the convenience of reference and account, were numbered, and were divided into four classes depending on the horizontal measurement. These classes were as follow:—

	Length.	Breadth.	Number.	Total Number.
1st Class	26	22	16	20
Do.	25	20	4	
2nd Class . . .	22	20	112	120
Do.	20	18	8	
3rd Class . . .	21	16	12	72
Do.	16½	14½	60	
4th Class	20	8	28	126
	22½	6	8	
	20	10	2	
	19	10	6	
	17	10	4	
	20	6	52	
	15½	6	26	
Total				338

In addition to the above, the flights of steps, built in the

form of quadrants, which terminated the aqueduct wings, and acted as curves to the embankment slopes on their reaching the aqueduct proper, were built upon circular wells, *of which there were four to each quadrant, or to each flank of the main building.* The total number of these wells was sixteen.

The plan of the foundations in all its detail is shown in Plate XXVII. of the Atlas. This plan exhibits the precise position of each block when first built, and as laid in the true alignement of the work. It also shows the state in which the *different blocks existed, after their undersinking* had been completed, and after the blocks themselves had passed through the ordeal of the downward movement which necessarily, more or less, affects their position. A careful observation of this plan is interesting as explanatory of the very small change that has taken place in sinking large masses of masonry to a depth of *20 feet, whilst in the smaller masses, especially* in those where there is an aberration to any extent from the perfect square, the movement is more considerable.

The method of under-sinking is practised by the natives of India (in the North-Western Provinces especially) to a great extent. It is universally adopted in wells for drinking purposes, and is largely used by their engineers *in obtaining supports for* their masonry works, when the soil is either sand, or of a treacherous nature. In such cases, cylinders of masonry are sunk either at distances apart or close together, and upon their tops, which are arched over and connected by masonry or other bonds, the superstructure is raised. In all the works which I had built upon the Eastern Jumna Canal, this species *of foundation* had been *used* with great success; and on the Western Jumna Canal, Colonel Colvin, who laid the foundations of the Dadoopoor Dam, had extended the principle by under-sinking rectangular masses of the

following dimensions, 15 feet long, 4 feet broad, and 10 feet deep; a good deal of the under-sinking being carried through small shingle. Colonel Colvin had, with greater or less success, also sunk the piers and abutments of small bridges which required deep foundations, the whole pier or abutment being under-sunk in one mass. The success with which this had been executed, showed that the principle of under-sinking might be extended to very large masses of masonry; and in planning the Solani Aqueduct, I extended it to cubes of 20 feet. This dimension, it will be observed, has been increased at the Dhunowri works, where the maximum horizontal dimension of the blocks is equal to 30 feet long by 30 feet broad, the depth to which they were sunk being 20 feet. In detailing the progress of the block-sinking I shall draw attention to certain laws which appear to guide the proportions of these masses of masonry, but in a general way the difficulties of sinking at all, and the danger of the blocks going down unevenly, increase as the form wanders from that of the square or the circle.

From the nature of the river with which we had to deal, the character of its bed and slopes, and the existence of springs on the surface, it was clear that there was no method of laying the foundations in the usual way by excavation. The alternatives lay between the European system of piles, and that adopted by the natives, of masonry under-sinking. In my own mind I had no doubt whatever of the relative value of the two; but as opinions were freely given by civil engineers whose experience had been derived from European practice, I may be allowed to state my reasons for selecting the native method in preference to that so much advocated elsewhere.

In the first place, in throwing expense overboard, it may be inferred that the use of piles in the early days of

building originated in an idea that it was impossible to lay masonry foundations to the depths that could be reached by piles. That *as long as this idea lasted, the* European engineer would, in cases like the foundation of the Solani Aqueduct, continue to use piles, and to depend upon them for the support of his superstructure. I am not aware, excepting in cases to which there is no necessity to refer here, as they are clearly exceptional ones, that either engineer or architect trusts to piles where he *can sink his foundations to a sufficient depth,* and get the security required without them. Possessing, as I did, the most ample resources for masonry under-sinking as adopted by the natives, by which the foundation would be carried to the required depth, why should I have adopted a method which is clearly an imperfect substitute? Nobody, I imagine, can argue that a building supported on a series of sharp points, standing on stilts, as it were, as is the case where piles are used, can be equal to that where it stands on a broad base, as is the result of the block system. On this *ground alone I select blocks in preference to piles.* Were the method of under-sinking comprehended in England, I believe that in fully appreciating its advantages, it would in all sandy and light homogeneous soils be adopted in preference to any other sort of foundation. We see, in fact, in some bridges lately constructed on the English railroads, an approach to the principle of under-sinking, and a recognition of the advantage to be gained by discarding the common pile. The iron cylinder which is subsequently filled with masonry, and the different inventions for depressing hollow masses by atmospheric pressure, are all tending to the right direction, viz., to substitute for points, surface.

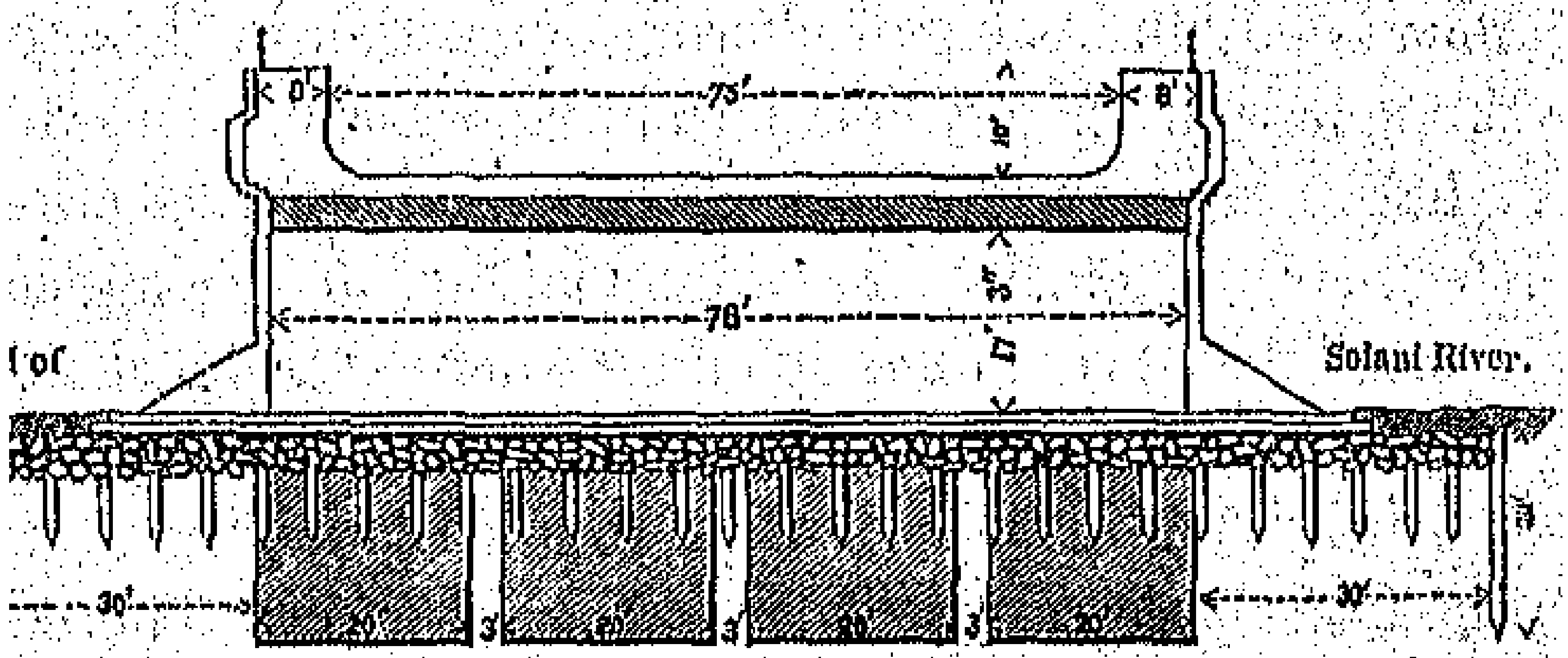
Expense, however, is a matter that, after all, is not to be dealt with lightly. At the Solani Aqueduct we could

only have used the largest species of timber, sticks that would have had to be brought from the forests in Rohilkund, on the left of the Ganges, with great difficulty, and at great expense. We should have had to construct very powerful engines at also a great expense; and we should have had to instruct our labourers in a species of work to which they were in a measure unaccustomed. The piling with its supergratings would have cost, including engines, repairs, and all the different contingencies to which such species of work is liable, at least half as much again as that of the blocks. It would have had, in my opinion, one solitary advantage only, and that is, that the length of pile would have admitted of our getting to a depth 5 feet below that of the blocks. Whether, in the face of a torrent, where the supersoil of the bed is in motion to considerable depths, and where the evils of percolation, and the escape of subsoil are by no means to be left out of consideration, it would have been worth while to go to a greater expense for a species of foundation most *remarkably incapable of offering opposition to these evils*, is a question upon which I think there can be no doubt. I have never felt the least distrust as to the selection of the masonry blocks for the foundations of the aqueduct, nor would I ever think of piling where such blocks could be used.

In boring in the bed of the river, the depths to which the irons were *carried did not exceed 87 feet*. There were no means at hand for prosecuting these inquiries to any great extent, nor did I consider that such were of importance as far as regarded the foundations only. As there was no intention of proceeding to extraordinary depths, I considered that soil lying 20 feet below the surface might be depended upon, and that if the subsoil on which the foundations rested was so far protected as to be kept out of the influence of current action we were as safe

20 feet as we should have been at much greater ths. With moderate depths of block sinking, moreover, should be more certain of securing an equability of er-sinking. To the depth of 37 feet, nothing was ıd but sand occasionally mixed with clay, but in ı small proportions that sand was clearly the pre-ıng ingredient. In practice, this was in a great sure corroborated, although many of the blocks have ced through and rest upon a soil of a much firmer sistency than we met with in the boring operations. blocks, however, may, be considered as resting upon l, protected both in their front and rear by curtains the purpose of maintaining the said sand intact, and from the *action of current, either direct in its pro-s* down the river, or indirect in its effect in eddies or ements caused by obstruction. The design will be understood by a diagram representing the original ι of 1840.

Diagram 148.



The above gives the aqueduct on proportions designed a much smaller quantity of water; but although ended in width to render it capable of carrying the er supply of the estimate of 1845, the details are the ıe. Here it will be seen that the front and rear are ered by sheet piling with a masonry apron, projected a distance of 30 feet beyond the body of the super-

structure. It was supposed that all action of the current would be limited to the extreme boundaries marked by sheet piling. The after improvement of substituting blocks for these lines of piling has still further increased the value of these protective curtains; and causes which will be hereafter explained have led to further modifications by which the action of the current is removed to a still greater distance from the body of the work. It will be comprehended by looking at the superficial area on which the base of each of the blocks on which the main building rests, extends, how much this adds to the stability of the foundations.

I now come to the practical method of undersinking the masses of masonry which form the support of the aqueduct, as in the common cylindrical well. A wooden curb (neemchuk) or frame is placed in the position in which the block is to be sunk; the masonry is then either built up to its full height, or only partly built; it is then permitted to stand over for induration. In my original design, each of the cubes was perforated by four cylindrical holes, an arrangement which was altered into square or octagon ones, as giving more space for the undersinking apparatus to work in, and as being more economical in construction. A common tressel windlass being placed over each hole, the soil is then simultaneously removed by means of the *jham*, which is a large shovel, or more properly speaking, a phaora, which is worked either by the hand at moderate depths, or by divers at levels below the spring water. To this there is a rope attached, which by the aid of the windlass is pulled up, and the soil with which the jham is laden is thrown out and removed. Professed well-sinkers were not, I believe, used in any part of these works, as in the first place we could hardly have collected a sufficient number; and secondly, it was found that the system

hich we adopted was so entirely our own, that it was easy to instruct the common labourers of the country work the jhams and to undersink the blocks, as it ould have been to break through the prejudices of the ofessed well-sinkers. The trade does not recognize indlasses, but works the rope over a pulley fixed on a ippoirt altogether detached from the well or block. By iis arrangement, the weight of both men and material, no means an element to be lost sight of in aiding the pression of the masonry, is sacrificed. We, on the conary, in using windlasses, brought the whole superinimbent weight to bear upon the mass, with at the same me a more economical application of the power. The am too that was used on the aqueduct works, had a ocket attached to the handle end of the blade, which ceived the end of a long pole, by the aid of which we ere enabled to work the machine to a depth of 20 feet, ithout the assistance of divers, or men actually in conct with the jham. I describe the system as it existed ter much experiment, and a great deal of tedious quiry, the greater part of which took place previously my return from England in 1848. To this tediousness experiment, the perfection at which the management the undersinking arrived, is undoubtedly due; and I lieve that to Lieutenant Yule, of the Engineers, and to r. Login, who was afterwards employed with so much edit to himself at the Dhunowri works, we are indebted r results which have been most satisfactory. The ay of undersinking the blocks will be much better iderstood by referring to Plate XXVII. of the Atlas, heets 5 and 6, where the work is shown in progress, and here the detail of construction of the brick-laying is also chibited.

With the removal of the soil from the interior, the pression of the block proceeds. It is necessary that

this should be uniform; and for this purpose, great attention is required to seeing that the four holes are equably worked, and that more soil is not taken from one hole than from another. Where the soil upon which the block rests varies in quality, much judgment is required in working the holes correspondingly with any inequality of depression that may arise from this want of homogeneousness: and, as it will be understood, much practice was required before we arrived at the perfection to which the latter period of our operations were characterized. As a guide to the well-sinkers, strings and plummets were appended to each side of the block, so that a departure from perpendicularity was easily detected. In cases when the simple means above described were inoperative in obtaining the uniform depression, and frequently when the rectangular narrow blocks were undergoing the process of undersinking when the departure from the perpendicular was very great, apparatus similar to that shown in fig. 2, Sheet No. 6, Plate XXVII. was used. Here a strong framework with a wide platform at its top, was fitted to the block, so as to obtain the most efficient leverage. The shape of the platform admitted of any amount of load so placed as to reduce the movement to equilibrium, or to force the sinking of the block in the direction that was demanded. This machine was of the greatest possible use in the smaller class of blocks, although not required in the larger.

The whole of the blocks of which the main body of the building consisted (*vide* Plate XXVII.) has been sunk, with exceedingly small disarrangement. The blocks themselves, it will be observed, are with a few exceptions only, nearly similar; the deviations being in the abutments, where they are still (although of different dimensions) of an equilateral form. To this fact may be laid the uniformity and comparative ease with which they

were undersunk, in contradistinction to that of the blocks which were substituted for the piles in the front and rear of the aprons, as well as to some of those which were appended to the wings. The plan (Plate XXVII., sheet No. 4) exhibits this remarkable difference in a very prominent degree. The sinking of these long and narrow blocks to the depths that were contemplated was, in fact, in a great measure, a failure.

The blocks to which I refer are numbered in the plan—37, 38, 51, 52, 53, 67, 68, 69, 83, 84, 85, 99, 100, 101, 115, 116, 117, 131, 132, 133, 147, 148, 149, 163, 164, 165, 179, 180, 181, 195, 196, 197, 211, 212, 213, 227, 228, 229, 243, 244, 245, 259 and 260 on the up-, and 49, 50, 64, 65, 66, 80, 81, 82, 96, 97, 98, 112, 113, 114, 128, 129, 130, 144, 145, 146, 160, 161, 162, 176, 177, 178, 192, 193, 194, 208, 209, 210, 224, 225, 226, 240, 241, 242, 256, 257, 258, 271 and 272 on the down-stream side; their dimensions are—

L.	B.	D.
22′ 6″	× 6′	× 20′
20′ 0″	× 6′	× 20′
15′ 6″	× 6′	× 20′

that is to say, it was intended that they should be sunk to a depth of 20 feet. When the commencement was made on the undersinking of these blocks, our men were well practised, and our establishment was fully instructed in all the different requirements for undersinking. The experience that we had gained on the equal-sided block, nevertheless, failed us altogether. I can compare the appearance of long lines of these blocks when in the course of undersinking, or sunk to a depth of from 7 to 12 feet, to a set of drunken men—one block leaning one way, another another, with an occasional division of eccentricity in a block going down head foremost. The position which they assumed, however, is well

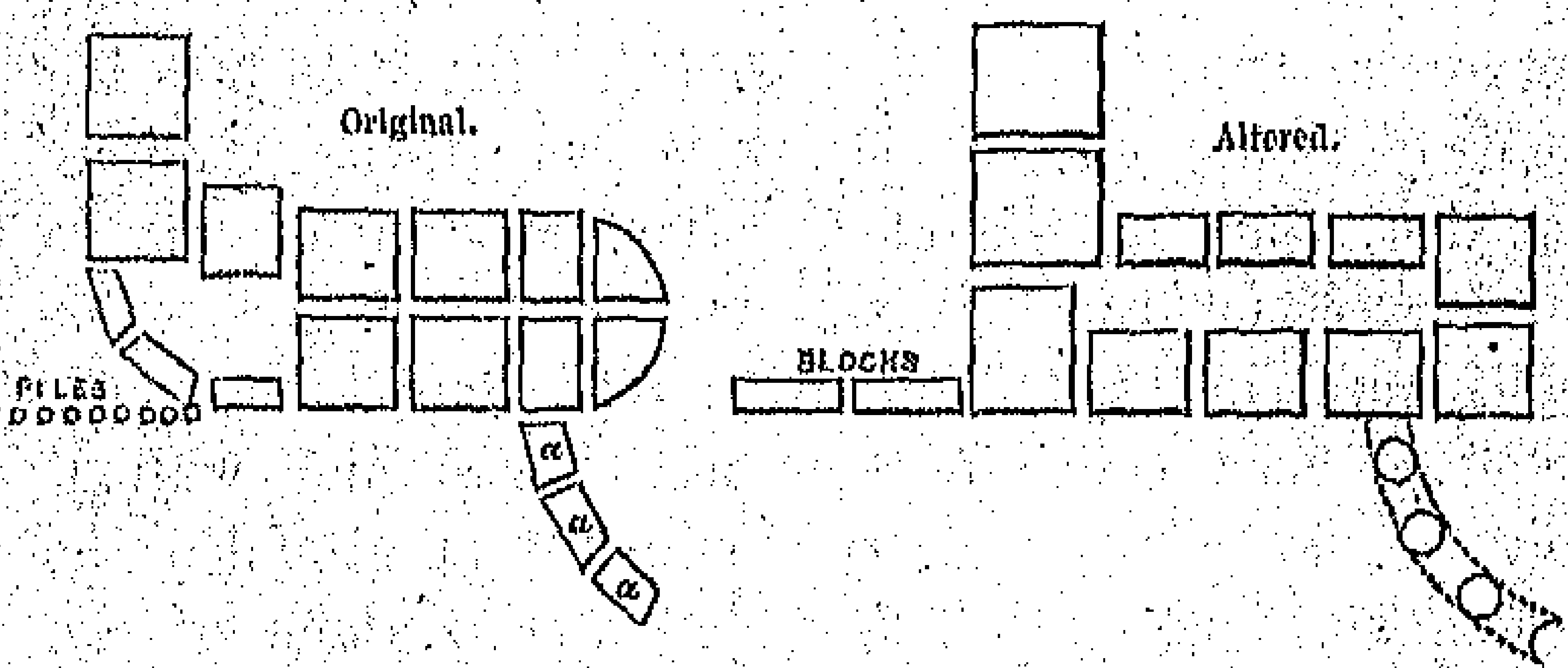
shown in the sheet of plans. Now, independently of the evil of this irregularity of depression, which disarranged the consecutive series, and, in many cases, the close contact of the blocks, which was one of the first desiderata, we failed in the main object of *depth*, which, as designed for the purpose of protecting the main body of the building, was indispensable. After continuing a long line of these rectangular blocks, without any hope of success, and at a cost that was frightful, from the impracticability of getting the masses to sink at all when they were much out of the perpendicular, Mr. Login proposed that an experiment should be made with blocks having the same area and shape at the *top*, but being wider at the bottom; making the block, in fact, like the frustrum of a wedge, two of the sides being perpendicular and parallel to each other, the other two sloping upwards. It was supposed that this breadth of base would retain a certain amount of equilibrium, and that the earth pressing on the sloping sides would, by its own gravity, facilitate the depression of the block. The experiment was so far successful that all the blocks remaining to be built were constructed on this design, and they appear to have been sunk to their full depth, and without any of the delays and obstructions that attended the rectangular blocks. The plans and sections of the wedge-shaped block will be found in the plate above referred to.

The result of this failure in the curtain or apron blocks was that the greater portion of those on the right of the river are not sunk to a greater depth than 14 feet, and the depth to which they have been *carried* is so irregular that I did not think it wise to place any dependence upon them. Lines of sheet piling, therefore, similar to those for which these blocks were substituted, have been driven both in front and rear; the former at a

distance of 15 feet, and the latter of 20 feet; the intermediate space between the piling and the blocks being filled with box-work, loaded with heavy material, and inclosed on its surface by sleepers. The same species of protection, in fact, which has been given to the bridges, falls, and revetments on other parts of the works. The foundation of the aqueduct, therefore, is protected now in a method that was not originally contemplated, but with a line of demarcation against the inroads of the torrent that must, I consider, secure the work from all danger.

The foundations of the wings were, as I said before, altered, in as far as both the position and size of the blocks were concerned. The original and the altered design are shown below.

Diagram 149.



The former gave an uniform and equal base for the superstructure to rest upon. The latter, although it decreased the expense, deprived the superstructure of the above benefit.

Economy, again, led me to substitute for the blocks *a*, *a*, *a*, above noted, cylindrical wells; a change which, with that of the wing blocks, may possibly have led to an inconvenience which will hereafter be described. At any rate both these changes from the original design

have naturally led to speculations on their particular merits.

In the early operations of block sinking much care was taken in recording the progress of block sinking. It was found that on a number of blocks the average rate of sinking of each description of block in one day, was—

Size of Block.	Rate of sinking per day.	
	Above 10 feet in depth.	Below 10 feet in depth.
	Running foot.	Running foot.
16′ × 21′	0·789	0·440
19′ × 10′	0·784	0·378
20′ × 8′	0·623	0·304
20′ × 18′	0·784	0·424
20′ × 22′	0·679	0·251
26′ × 22′	0·638	..

This does not, however, give any correct index to the rate of sinking of blocks throughout the work, as there are many and varying elements affecting both progress and cost. In Appendix O, an interesting paper drawn up by Captain A. G. Goodwyn on this subject, though not entirely complete, shows in considerable detail the operations carried on under his supervision. With this and Lieutenant Yule's results before me, I find that the average rate for each class of block sinking over the whole of the work, was—

Description.	Rate per running foot in depth. RS.	A.	P.
1st Class	16	8	9
2nd „	16	6	4
3rd „	9	14	4
4th „	9	1	6

Every expense being included, *except that for the curb frames upon which the blocks rest.*

The use of strap *iron* (*or wine plate*) was largely

made in the early part of the block building. It gave, I doubt not, additional strength, both in bond and by oxygenation of the metal, to the cement. Its expense, however, was very heavy. As the masonry, both brick and mortar, was of a very superior quality, I discontinued its use, on the strap iron which we had in store being expended. The method of applying this iron in bond is shown in fig. 1, Sheet No. 5, Plate XXVII., together with the skew-backs for the reception of the arches by which the undersinking holes, refilled with the soil which had been previously taken from them, were covered, before raising the superstructure upon them.

We will now suppose that the whole of the blocks are sunk to the full depth, that their undersinking holes have been arched over, and that preparations have been made for completing the floorings.

The blocks, it will be observed on reference to the plan, were, previously to the commencement of undersinking, placed at short distances apart, so as to admit of irregularity of depression, and to avoid contact or friction with each other in their progress downwards. The distance between the large class of blocks did not exceed 2′ 3¾″; that between the smaller ones, 2′ 11″. The first thing that was done before a commencement was made to the floorings, was to drive piles 12 feet in length, so as to fill up the spaces that existed between the blocks. This was done merely on the outer sides, so that as far as possible the external defences might be continuous. The distance of separation between these masses of masonry had in the progress of sinking become somewhat different to what it was originally designed; but, whatever the distance was at this particular period, piles were driven so as to occupy the whole space. On the completion of the pile driving, which divided the

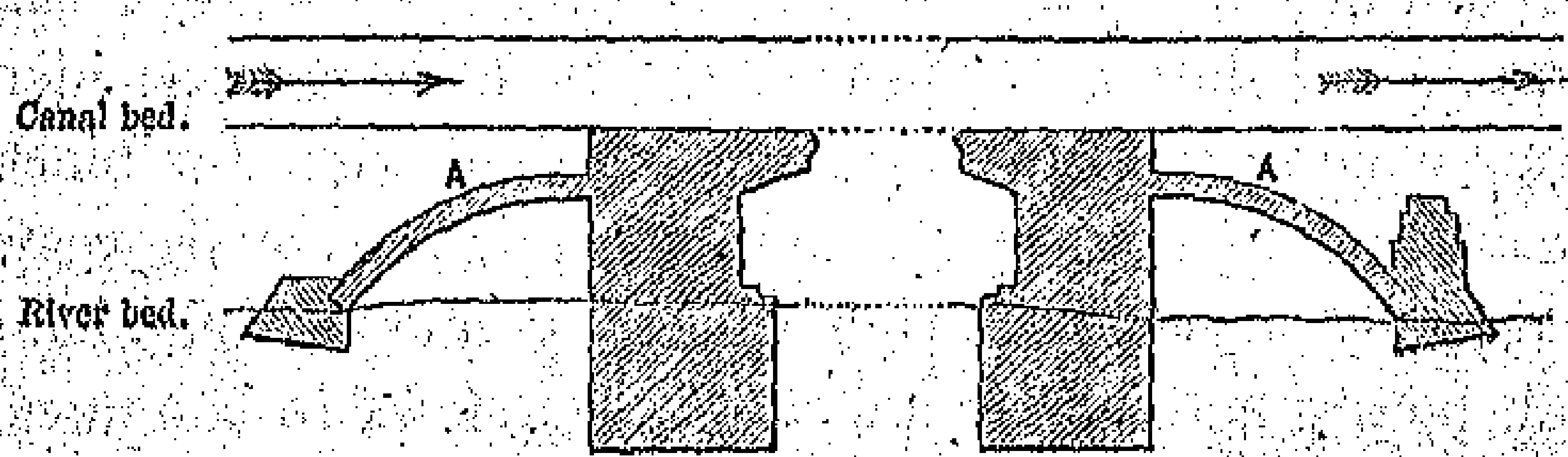
whole of the foundations into a series of tolerably compact caissons, the sand and earth were excavated to a depth of 8 feet, the spring-water being kept down by baling. The whole was then filled in with rubble masonry, carefully laid and grouted, so that the utmost compactness might be attained, and the upper surface was covered with a flooring of bricks laid edgeways. I consider that the whole of this work has been very effectively done, and the system adopted by the assistant engineer in charge of the building (Lieutenant Price), of laying the work in bits or small portions, so as to secure an effective use of the baling apparatus, enabled him to lay in the masonry unimpeded by spring-water, and, consequently, to secure the most perfect work.

During the progress of the floorings, a work that terminated during the season of 1853, a commencement was made to the superstructure. At this time the blocks had many of them been sunk for upwards of 5½ years, especially those in the right abutment and its neighbouring piers; and it was an object, therefore, to commence the superstructure on that side, gradually working towards the left, so that the whole of the blocks might have the advantage of the longest available time for settlement.

At this period, I undertook a careful revision of the details of the superstructure as originally designed, and, taking advantage of the increase that had been given to the width of the abutment, I decreased the rise or versed sine of the segmental arches, making them similar to those which I had elsewhere adopted, viz., 60°, or one-sixth of a circle, and reduced the thickness of the arches from 5 to 4 feet. This enabled me to give increased waterway, and to raise the spring of the arch to a height of 12·45 feet above the bed of the torrent, a very great advantage to the capacity of the channel, as well as to the external appearance of the elevation. The up and down stream

ends of the masonry aqueduct connected with the canal channel, and the abrupt transition from the masonry flooring of the one to the earthen flooring of the other, was also at this period a matter of much anxious consideration. Both at the point of ingress and egress of the current upon the floorings, a certain amount of action was certain, and this action could only tend to disarrange the bed in immediate contact with the abutments. To prevent this, therefore, and to remove the current action to a distance, aprons of masonry were placed in rear of the abutments, so that the water could only act within certain well-protected limits. The following diagram will show the design of this portion of the work:—

Diagram 150.



A A being the aprons with their abutment blocks. That on the up-stream side, it will be observed, has its block raised to a height merely sufficient to support the arch, whilst the down-stream block is elevated. My object in this arrangement was to offer obstruction to the current in its onward movement, supposing that there should be inclination to excavate, and to form holes, as might be expected at these particular points where the force of the current was onwards as well as downwards. On the up-stream side, the action being different, a different remedy was adopted.

The wing buildings were carefully worked out in detail, and, although not actually intended for the immediate purpose of mills or machinery, were fitted with

pipes for the delivery of water-power. The design included, also, measures for denoting the high-water mark both of floods in the Solani and of the canal supply, by apparatus placed on the flanks of the aqueduct, whilst the wings themselves were crowned by plain pedestals, surmounted by lions.

The elevation of the faces of the work (with the exception of the spandrils being pierced for ventilation) remains much the same as it was formerly.

The plan that I originally adopted of building the superstructure in two separate lines, and of making the canal waterway in two separate channels, was maintained in the final revision. The total width of the work was 192 feet; the piers, therefore, were raised in portions of 96 feet in width each, merely touching each other and free from brick bond. There were sundry advantages in this plan, the greatest of which was its admitting of irregular settlement of the foundations without disarranging the whole area of the superstructure. Great facilities were also given to the construction of the arches, as by the proposed plan the surface over which settlement might be expected on removing the centerings, was reduced to one-half, whilst the quantity of ribs and apparatus for building the arches were reduced in an equal proportion. In having two channels for the passage of the canal water, moreover, we held in our hands the means of repair without the necessity of closing the canal. The design (*vide* plan) admits of the closing of one channel and laying it perfectly dry, whilst the other affords a free passage to the water. Another consideration that led me to the division of the passage over this aqueduct into two channels, was the probability that, on an extended surface equal to the whole width, the effect of the continued north-westerly winds which blow transversely to the line of aqueduct, might be prejudicial in causing waves, and a

lateral action upon the side walls or revetments which might endanger their stability. The intervention of a central wall would in a great measure, I imagined, remedy this inconvenience.

It will be observed that at each end of the chambers, the waterway is divided by piers for the reception of sleeper-planks, which can be dropped through grooves formed for their reception. The closing of the ends of one of these chambers prevents the admission of further water, whilst small sluice shutters connected with side channels carried through the revetments towards the escapes in the wing building, give facilities for carrying off the water which remains in the chamber after its ends were closed. The chamber being thus laid dry, any repair required may be easily effected. The piers above described give supports also for lines of cross-communication from one side of the aqueduct to the other, obtained by the sleeper-planks, when not otherwise required, being thrown from pier to pier.

The spandrils were filled in by cross walls, as shown in the plan, pierced by archways, and opened out to the external air by means of the circular holes which appear in the elevation on the pilasters. These round holes give free ventilation to the whole of the space connected with the spandrils, which, by means of the archways above noted, are accessible in all their parts.

The thickness of the masonry between the soffit of the arch and the surface of the flooring of the chamber is 5 feet, 4 of which constitute the arch, and the remaining foot is of flat brick. The level of this flooring coincides with that of the Roorkee Bridge, a part of the design which will be hereafter explained when describing the general levels upon which the aqueduct has been laid.

The tops of the side revetments, which are 10 feet in width, are furnished with single lines of railway in con-

nection with those which extend along the embankments. The sides of this revetment or roadway are protected by iron balustrades.

The above, with the Atlas plans, will enable the reader to obtain a fair estimate of the design as it existed at the period when the superstructure was commenced. I shall now proceed to give an outline of progress during its construction.

On the completion of the piers to the full height, including the skewbacks or impost blocks on which the arches were to rest, the single line of railway, which I have described and figured in diagram 138 as running from the Roorkee brick-fields to the bridge, and from thence on an inclined plane to the level of the top of the cutwaters, had been gradually, and as the masonry had advanced to a sufficient height, pushed across the Solani to meet a similar line which had been made branching off from the double rail on the Muhewur side. The completion, therefore, of the up-stream cutwaters, and, consequently, the line of single railway, gave us a connecting link between the brick-fields at the extreme ends of the aqueduct works, and enabled us to concentrate all our selected material for arch building on the field of our operations. The railway to which I am now alluding, as connected with the tops of the up-stream cutwaters, was carried across the 50 feet bays by the interposition of two temporary piers in each bay, the width of each being 3 feet, and its height 10 feet. Each 50 feet opening, therefore, was divided into three bays of 14·66 feet in width each. The rail was supported on timbers of 12 inches square, or of the common size brought from the forests, laid longitudinally across the pier-heads. There was by this arrangement a free, although somewhat interrupted waterway for the torrent along the whole line of the work.

The material for each arch was collected immediately on the spot where it was required. It was deposited on platforms arranged for its reception in contact with the railroad, as well as on the tops of the piers themselves. The bricks were of the best sort procurable from our manufactories. They had been in progress of selection from the early periods of our brickmaking, and, although many of them required cutting and squaring to adapt them to the particular purpose for which they were intended, they were without doubt of a first-rate quality.

Before proceeding to a description of the arches and their centerings, I shall take the opportunity of detailing events which had occurred at this period of the progress of the work, that is to say, from the commencement of block-sinking up to the 1st of December, 1851, or the date when the first brick was laid in the arches.

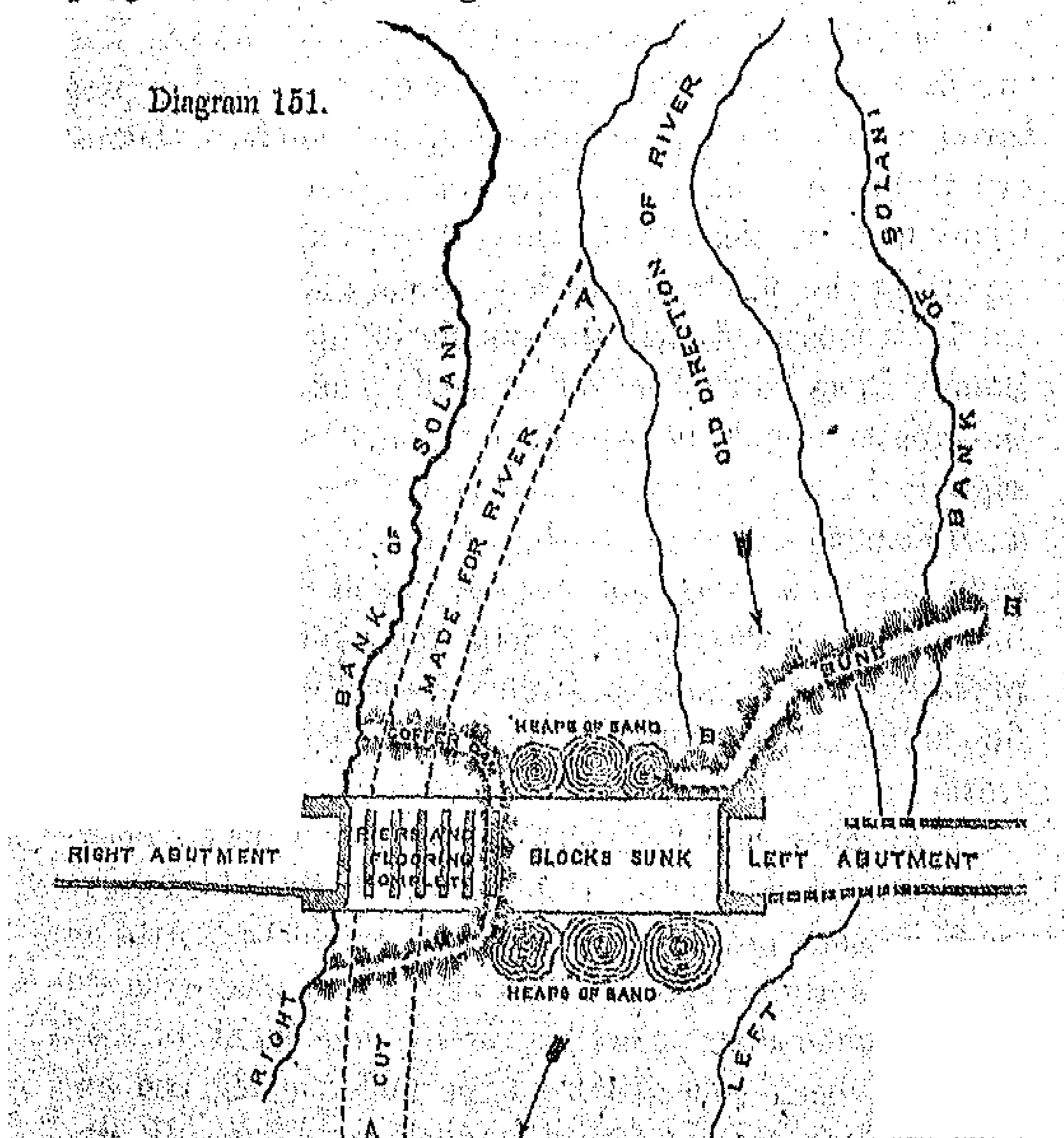
In January, 1848, when I rejoined the works, a coffer-dam or embankment had been thrown round the whole of the blocks which were in progress. This coffer-dam encircled the right* abutment and its neighbouring piers, and it was under the protection offered by this enclosure that the work was continued through the rains of 1848, and partly through those of the following year. When the rains of 1850 were approaching, the progress that had been made on both flanks, in the raising of the abutments, and in partly connecting them with the earthen aqueduct revetments, made it necessary that we should endeavour to restrict the torrent to a course bounded by the abutments. There were no difficulties opposed to the measure, and the only danger that we incurred was from the imperfect state of the earthen aqueduct revetments on the left, which at that period

* In describing the aqueduct, it may be useful to note that I use the terms "right" and "left" with reference to the course of the Solani River.

were very incomplete, and in such a state that I considered it necessary to protect them from the torrent, and from the action of water in its passing down the river.

At the commencement of the rains of 1850, the state of the works will be understood from the following diagram, in which I have noted the bunds and cuts which were made previously to the rains of that year for the purpose of protecting the left flank and abutments, and of making the river clear away the coffer-dam, as well as the mountains of sand that had been collected during the progress of block-sinking.

Diagram 151.



The course of the river, it will be observed both from

the above diagram and from the map in which the river works are figured, bore at this period directly upon the left flank and upon the rear of the abutment. There was a considerable bend in this course on the approach of the river to the works, and advantage was taken of this bend to make the cut A A bearing upon the right flank, the coffer-dam having been cut through on both sides. The heaps of sand figured above between the coffer-dam and the left abutment were eased off so as to give passage to the water; and the left abutment itself, with its half-finished revetments, which are shown by thick dots, was covered by a strongly built embankment and spur. As this was the first year that the torrent had been required to pass through our artificial boundaries, its conduct (taking everything into consideration) was not so capricious as it might have been. On the 5th of August, 1850, in reporting the effects of the floods upon the Ganges Canal works, I observed that the results of the floods at the Solani River have been of exceeding interest. "Both the abutments of the aqueduct through which the passage of the river has been effected, had been completed to a sufficient height, and, although the revetments on the right and left were not entirely finished at the commencement of the rains of 1850, embankments and other protective works were so arranged, that the whole of the floods might pass through the waterways of the masonry work.

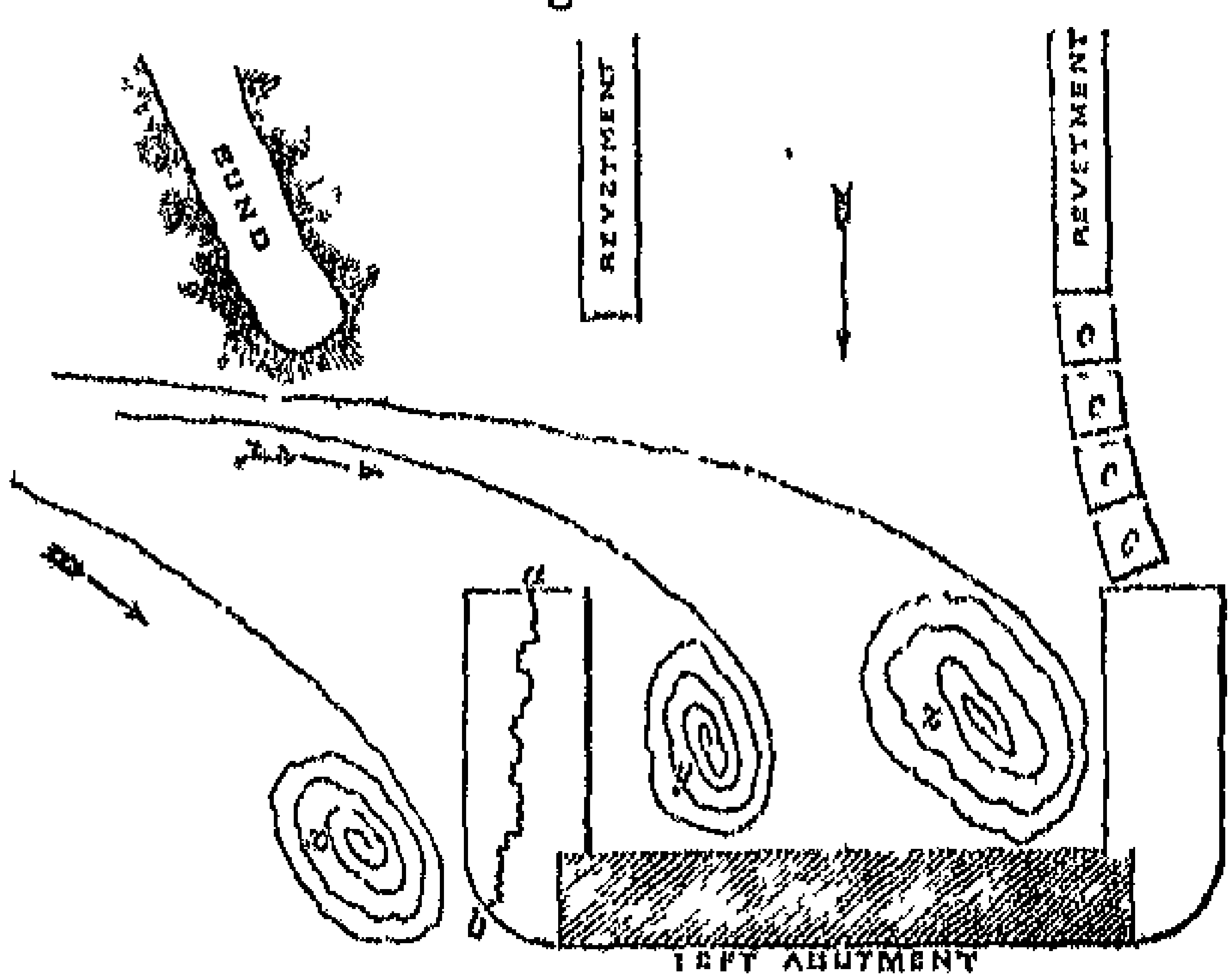
"A coffer-dam had been thrown round the six openings and piers on the right flank, so that during the rainy seasons previous to 1850, work might be carried on independently of floods. The object now was to get rid of this coffer-dam as well as of the mountains of sand that had been collected from the undersinking and excavation for the masonry foundation blocks. It was determined, therefore, that the early floods of 1850

should be the power employed for obtaining this very desirable result, and the executive engineer's attention was directed to such arrangements as would lead the water through a channel prepared for its reception across the coffer-dam, and impinging on the right abutment of the work; it was also determined that the main body of the floods should be confined to half the full extent of the waterway, or to seven of the bays or openings of 50 feet in width each, as shown by the above diagram."

In the same report I state that "the above works have been most successful; enormous quantities of the collected rubbish have been swept away, and the whole river now, instead of bearing on its old course upon, or rather through, the left abutment, passes over the site of the coffer-dam, and through the piers, which on that side have been completed." The engineer in charge of the works reported that during the time when the floods which effected this clearance were running, and whilst the water was confined to three bays, there was as much as 12 inches of fall on the length of the piers (192 feet), but as the obstruction of sand gradually diminished it became level. The water rose on the piers to a height of 7 feet 4 inches above the flooring, falling over the sides in a heavy cascade. Subsequent to the date above referred to, and during the month of August, 1850, a succession of floods gave some trouble. The embankment on the left, marked B B, diagram 151, was washed away; and the water, by getting in rear of the abutment, and amongst the unfinished and half-sunken blocks of the revetments, did some damage and caused a slight settlement to the left up-stream wing of the abutment. In reporting the effects of these floods, I remark, "that, as the blocks which have been disarranged, and the consequent crack that has taken place on the superstructure, are quite independent of the body of the aqueduct and of

the abutment upon which the arches will rest, the injury is of no consequence to the work, although additional outlay will be required to restore matters to their former condition. I may further explain that on this, the left side of the aqueduct, neither floorings nor curtain blocks have been completed, so that the current in its progress was able to exert its full action. The absence of connecting walls from the revetment to the abutment flank, permitted the floods to get behind the abutment, an evil that I had tried to prevent. Nevertheless, taking everything into consideration, the damage done is less than might have been expected." The following diagram shows the direction of the current, and its method of action when it came in contact with the masonry:—

Diagram 152.



a, y, x. Holes excavated by the current.
c, c, c. Blocks standing uninjured.
a b. Crack on the wing.

The shaded portion represents the abutment which is connected with the skew-backs and arches of the building.

The crack was dependent on the excavation *x*, and the declination of the wall from the perpendicular was 1·25 inches at its maximum point. It was not con-

sidered necessary to remove the building which had at that time been carried to a height of 10 feet, but the hole excavated at x was filled in with heavy material, strengthened by piling, and all other means were taken to remedy the defect, as well as to prevent any further continuation of settlement. The rains, which usually terminate in September, did no further damage. The good that they had done on the opposite flank in clearing away the coffer-dam, and in removing the sand, was incalculable. On the whole, and considering the extent of the floods during 1850, we escaped with very moderate injury.

The cold-weather rains of 1850-51 were unusually severe, but the floods that came down the river at this period passed off without any damage worthy of notice.

The rains of 1851 brought down numerous floods, and tried the aqueduct at a period when the flanks, the intermediate piers, and the greater part of the floorings, were completed. From this year may be dated the passage of the Solani through the bays of the aqueduct, and when the masonry works in connection with the torrent were prepared for its reception, the maximum high water during the heaviest flood of this year stood 6 feet on the piers; this season passed off without any disarrangement to the works.

On the 1st of December, 1851, the building of the arches commenced, and they were carried on without interruption until the 4th of July, 1853, when the last arch was keyed.

It was my intention at the period when the aqueduct was designed, to have used earthen centerings, which have the merit of cheapness and simplicity, combined with other attributes, which in my idea rendered their use at this point very desirable. The results, however, of using centerings of this description on the line of canal below Roorkee, in building arches of 55 feet span,

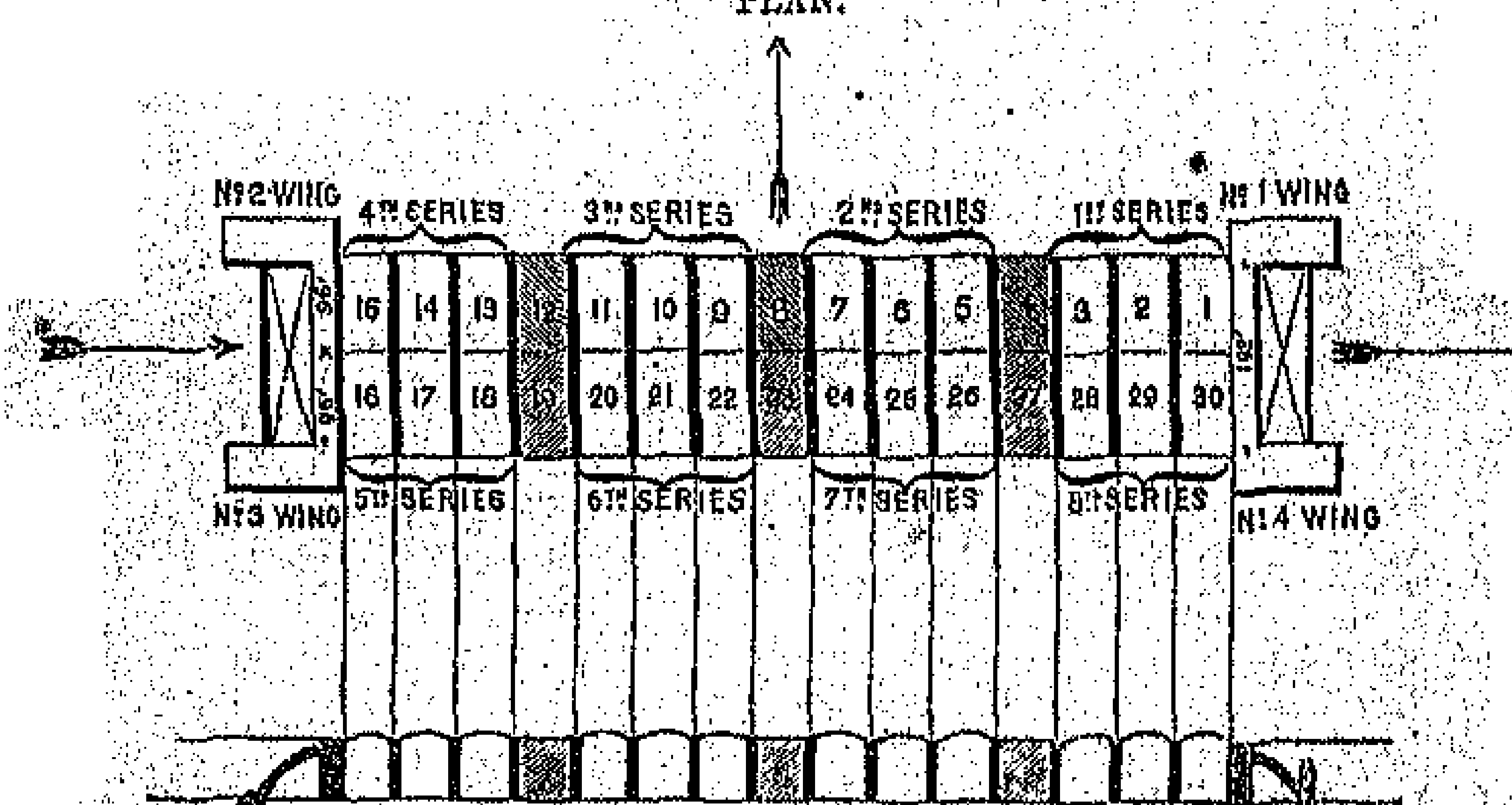
were decidedly opposed to their introduction on the aqueduct, where, although the span was less in width, the thickness and consequent weight of the arch were greater. I have in the chapter on Bridges, when describing the different species of centerings which have been used on the works, entered fully into the causes which led me to reject these simple centerings at the Solani Aqueduct. As I had failed altogether in devising any satisfactory expedient by which I might preserve the form of the arch, and at the same time escape from a direct rigidity of centering, I determined on resorting to the European method of timber ribs, and with this object Captain Goodwyn, of the Engineers, the executive engineer at Roorkee, commenced a series of experiments for the purpose of determining the best sort of frame that could be made, at the smallest cost, and with the least injury to the timber that it would be necessary to cut up for the purpose. It was our object, as far as possible, to take advantage of the species of sawn-up wood that was for sale in the market, and at the same time that we secured efficiency to obtain a species of centering that would interfere as little as possible with the waterway, and be quickly and easily removed.

The results of Captain Goodwyn's experiments led to the adoption of a species of centerings which I shall describe presently, and to a method of limiting their number, by building the arches in detail, which, both as regards economy in the construction of the work, and conveniences for passing off floods during the operations, was of the greatest value. The plan that Captain Goodwyn proposed was, that, by converting certain bays into abutments, the arches might be turned in a series of independent works, for which only a limited number of centerings would be required. By adopting this method, we should be able to have three-fifths of the

bays of the aqueduct always open for the passage of floods, and by confining our arch-work within moderate limits we should be better able to economize our men and our material. The proposition was an excellent one, and it has been adopted with all the success that could have been anticipated. The arch-building, as will be understood by the following diagram, consisted of eight independent series of triple arches, resting on temporary abutments, formed by building walls across the bay adapted to the ultimate support of the centerings, the spaces between the cross walls being filled in with sand.

Diagram 153.

PLAN.



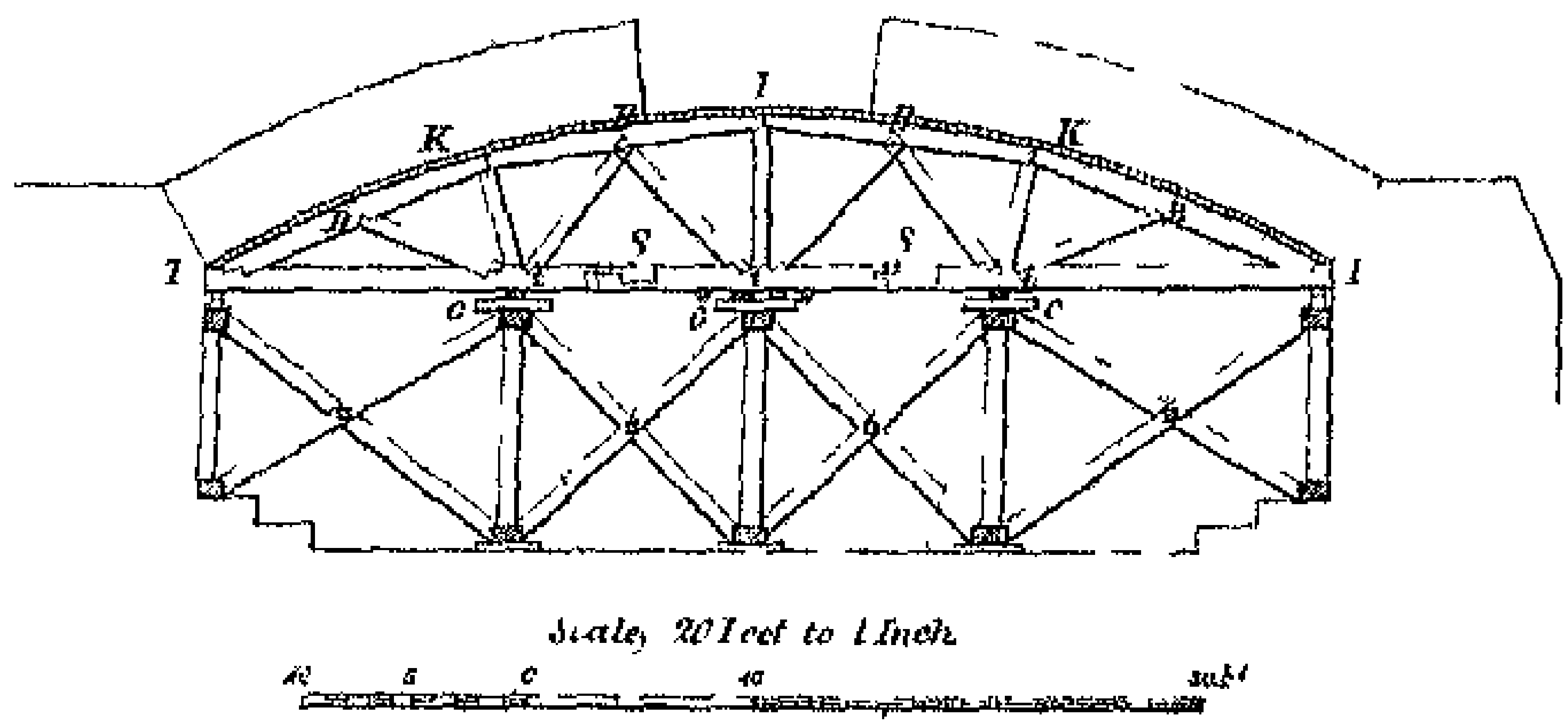
Longitudinal Section.

It will be observed by the above diagram, that, by the division above mentioned, each series is conducted independently of its neighbour. From the circumstance of the aqueduct on its full width of 192 feet being divided into separate portions of 96 feet each, the whole work resolved itself into an up-stream and a down-stream line, constituting eight sets of arches, or eight independent series of works. During the period, therefore, that the building of the arches was in progress, nine out of the fifteen bays, giving a clear waterway of 450 feet in width, might always be open to receive floods.

DIAGRAM CLIV

SOLANI AQUEDUCT
CENTRES.

Fig 1
End Elevation of Centre



Scale, 20 Feet to 1 Inch

Fig 2
Elevation shewing method of moving Supports of Ribs

Scale 12 Feet to 1 Inch

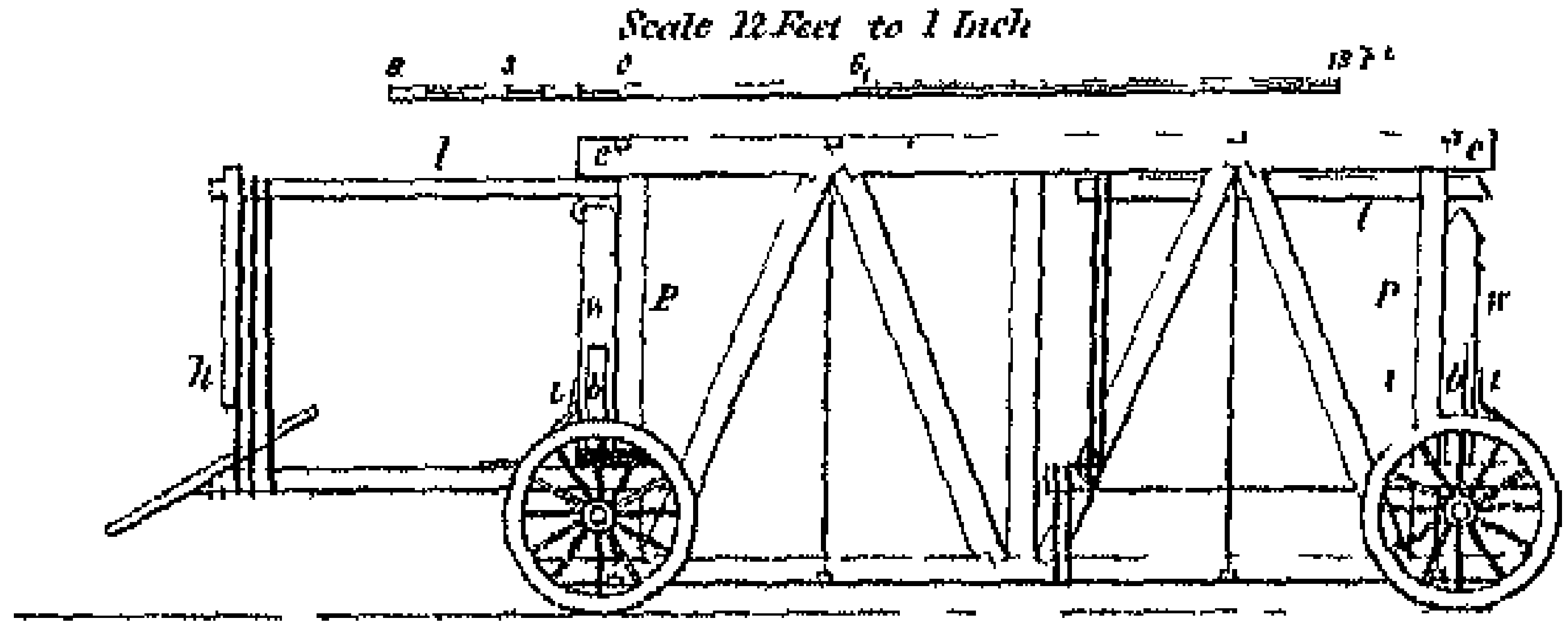
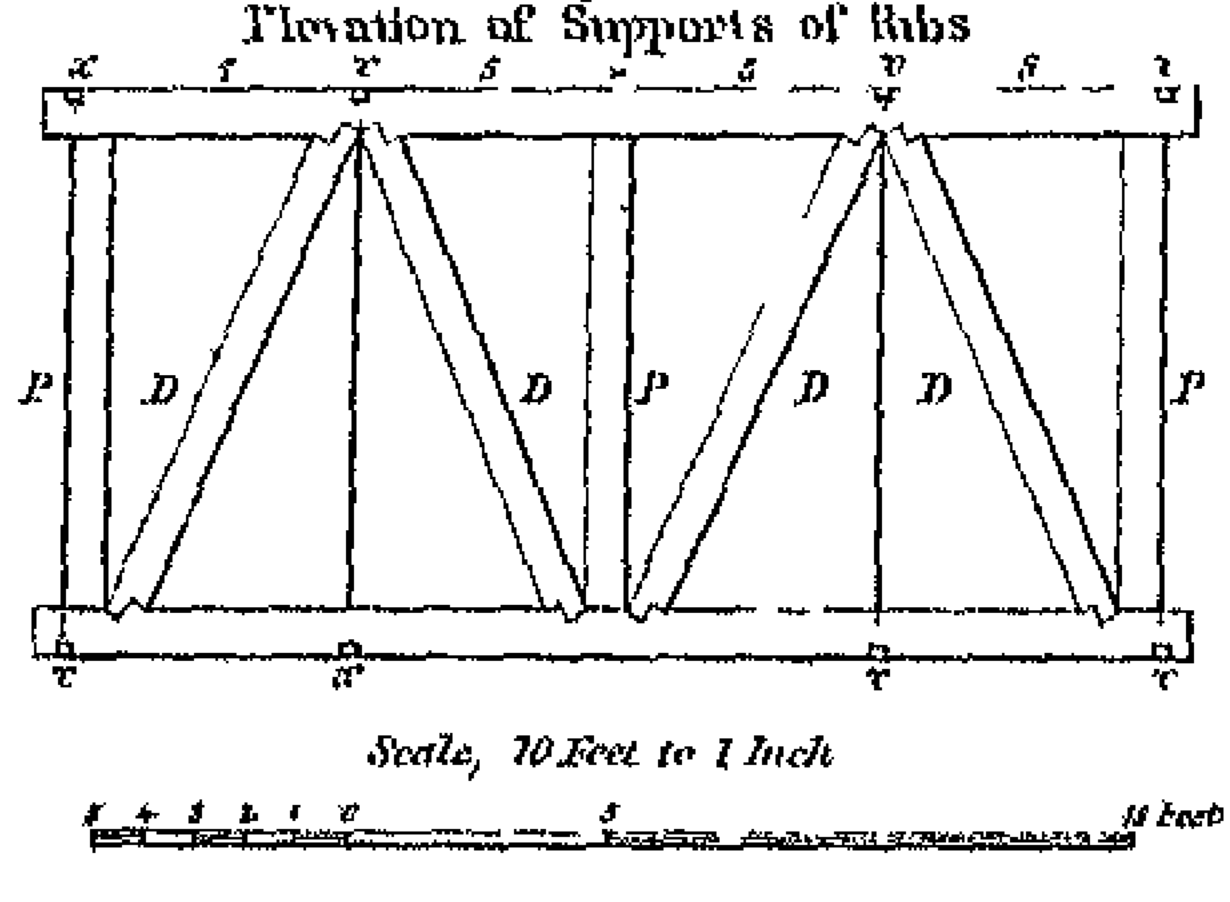


Fig 3
Elevation of Supports of Ribs



Scale, 10 Feet to 1 Inch

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The construction of the arches in the series above noted, commencing on the right down-stream side, was dependent on facilities for obtaining material which that plan preserved over the other which was open to us, of completing each bay on its full length. The plan adopted also gave us at an earlier period a communication across the aqueduct.

The above arrangement having been determined on, the quantity of woodwork required was limited to that for three bays, each of which was 50 feet in width and 96 feet long. Captain Goodwyn, in making his report to me on the conclusion of his experiments, and after having put his centerings in practice, writes thus :—

"After it had been decided that the aqueduct should be arched from shore to shore in two half widths of 96 feet each, the distance at which the ribs of the centerings should stand from each other was regulated by the scantling of the 'Brinjarri kurri,' which, for the support of an arch 4 feet thick, permitted those ribs to be distant from each other 5 feet from centre to centre, without itself suffering appreciable deflection.

"In designing the ribs, having in view the expressed wish of the director of the works, in which I fully concurred, that the centres should be struck immediately on the arches being keyed, and whilst the masonry was as fresh as possible, a continuous tie-beam, T T, fig. 1, the upper surface of which represented the springing line of the arches, appeared to afford greater facilities for regulating the striking, as well as the adjustment of the centres before commencing the archwork, than supporting the bearing pieces, B B, at once from the flooring. To make a tie-beam 50 feet in length, however, two scarfs, S S, were indispensable, owing to the short length of timber available; and this, with the advantage of giving the bearers, B B, as many trussed points as pos-

sible, thereby stiffening the framing and rendering timber of comparatively small scantling available, induced me to give the tie-beams five points of support, as the most economical arrangement.

"Having these fixed points T *t t′ t* and T, four stable intermediate fixed points, B B B B, immediately resulted; *and the lower surface of the pieces* B B B B *was divided* into eight equal bearings. Lines drawn from K to *c* gave the direction of the radiating supports of the bearers, and where these lines intersected the lower surface of the tie-beam were fixed the points *t t*, where the supports from the flooring could be most advantageously applied.

"No centre can be said to be well designed which is subject to change of shape whilst being loaded. Had T K L been in one piece, the weight of the arch masonry in progress from the sides of the arch towards the centre, as it approached K, would have raised up the end L, disarranging the dressed surface prepared for the intrados of *the arch. The pieces* B B *were therefore unconnected* at K, though touching. At L, a space of 3 inches was left between the bearers, thereby allowing the tie-beam T *t′* T, to be deflected when necessary 4½ inches in the centre, the points T T being still fixed, without the ends of the bearers B B coming in contact at L. It was not supposed that the arches would sink as much as 4½ inches on the centres being struck; had they done so, however, and had more room for lowering been required, it could have been obtained after lowering the points T, which were supported by wedges, with this object in view.

"The supports for the points T *t t′ t* T are shown in fig. 2. They consist of rough beams dressed on their *outer surfaces parallel to each other*, and of such lengths between the limits of 22 and 28 feet as our stock afforded. These parallel beams were united by three perpendicular

ones, P P P, of strength calculated sufficient to resist the downward pressure at the points T t and t', and the intermediate points between P P P were trussed by the diagonal braces D, each pair of which was of the same aggregate strength as the vertical pieces P. The whole frame was then bolted together by four wrought-iron suspension-rods, as shown at x x x x, and became very strong and compact.

"Twenty such frames are required for the centering of each half width of arch (96 feet). They are very massive, but notwithstanding this, they have never been taken to pieces after having once been put together, and are moved bodily in a vertical position, by a simple contrivance which I will describe.

"Pairs of wheels with axles and poles were fitted with upright pieces of timber, fig. 2, set perpendicularly on the axles, about 5 inches from their middle. These uprights are kept in position by wooden braces or shores, b, the lower ends of which are fixed on to the axle-trees, and by iron braces i, fixed fore and aft, on to the poles. The poles were kept rigid in an horizontal direction at the point of attachment to the axle-trees by similar horizontal iron braces at two opposite right angles formed by the crossing of the poles with the axles, thereby leaving room for the carriages to be backed or drawn close up to their work, which, if four such braces were given, could not be done. The adaptation of levers on the tops of the uprights w, will be understood by inspection of the diagram, fig. 2.

"When it is desired to raise the frames, which it must be remembered have been left in a vertical position after the removal of the curved ribs, the levers l are raised by means of the handles h, and their short ends are, in the case of the leading carriage, brought under the ends of the frames e, by the carriages being backed. The

upright pieces *w*, having been brought in contact with the end pieces P of the frames, the handles *h* are drawn down, and the frame is lifted fairly off the ground and hangs suspended from a small spike at the end of the lever *l*, which serves as a pivot. The uprights *w* are then lashed to the pieces P (the levers and poles having been previously lashed, as shown in the diagram), and the machine is ready for travelling. In the case of the rear carriage, it is evident that the end of the levers *l* cannot be got under the end of the frame *e*; this obliges us to use a crowbar at right angles to the lever *l*, giving a cross lever.

"The fore-wheels will now turn in one direction, and act like the fore-wheels of a carriage. The head of the machine can be turned from right to left, which is all we require, and the whole runs over the masonry floor of the aqueduct with great ease, carrying its load in a vertical position, and depositing it in the same position on its new site; after which it is prevented toppling over by five-yard kurries, set across each other as diagonal braces, and lashed at their centres.

"Above these supporting frames thus arranged, and astride of them, are laid pieces of timber $3' \times 1' \times 5''$, *c c c*, fig. 1. In the case of the central point t', where the amount of lowering necessary to clear the centres from the arch is greatest, and where powerful screws 3 inches in diameter with a pitch of one-third of an inch working in brass boxes, are used blocks of wood, *w w*, sufficiently distant from each other to admit the screws being inserted when necessary, are set, bearing upon the tie-beams. By keeping the screws away until they are wanted, risk of theft is obviated, and they are preserved from injury by dripping of water on them whilst the masonry is in progress. Under the lateral points T T, however, pairs of wedges are inserted, and, as the weight borne by them is

very considerable, the projection of the pieces *c c* on each side is valuable, as affording the means of applying as many pairs of wedges as may be required; thereby lessening friction on each, which renders it difficult sometimes to start a single pair, especially when their ends are bruised.

"After the completion of the masonry, the screws are inserted and are screwed up, their heads working on wads of steel, until the blocks *w w* can be struck out. A simple kind of gauge is applied to each of the points *t t* and *t*, and the operation of striking is then commenced. Corresponding points in adjacent ribs are never allowed to differ in level more than one-twelfth of an inch, equal to a quarter turn of the screws from each other. Three intelligent men are required to superintend the lowering of each set of centres, and I prefer having an acknowledged difference of level of one-twelfth of an inch between adjacent corresponding points, to the greater, though unacknowledged, difference that would result if a crowd of people, sufficient to man each point, were turned on to the work, few of whom would have eyes equal to the measurement of a twelfth of an inch, even if they had ideas of what it was, or what was required of them."

I have preferred an introduction of Captain Goodwyn's own account of the process that was carried on, as, with the appended drawings, nothing will be left for further explanation. The modifications that experience showed to be necessary were comparatively trifling, and hardly worthy of record. It will be seen by the table of dates at which the series of arches were begun and completed, that practice rendered the transportation of the centering from one place to another, their fixing, and preparation for the arch, a simple and therefore a speedy operation.

TABLE showing Dates at which the Arches appertaining to the different series noted in diagram 158, were commenced and completed.

Number of Series.	Date of Commencement.	Date of Completion.	Number of Days occupied in their Construction.
1	1st Dec. 1851.	31st Dec. 1851.	31
2	9th Feb. 1852.	29th Feb. 1852.	21
3	12th April "	30th April "	19
4	19th June "	11th July "	23
5	13th Dec. "	2nd Jan. 1853.	21
6	21st Feb. 1853.	10th March 1853.	18
7	13th April "	30th April "	18
8	21st May "	5th June "	16

ABUTMENT BAYS.

4	17th May, 1852.	4th June, 1852.	19
8	"	"	19
12	21st July, 1852.	9th August, 1852.	20
19	15th June, 1853.	4th July, 1853.	20
23	"	"	20
27	"	"	20

Although my great object in using timber centerings was to avoid the separation of the bricks in voussoir at the haunches, an evil which was so conspicuously brought to my notice wherever earthen centerings had been used, we have not escaped from this defect in the aqueduct. It is a remarkable fact that this separation, small and insignificant as it really is, has invariably taken place at the same distance from the skewbacks as I have in a former chapter described as universally occurring in the bridge arches. For instance, the engineer reported that "during the building of No. 1, and when the masonry had reached to a distance of 5 feet from the abutment, a very fine hair crack or separation on the line of voussoir took place about 1 foot from the impost block." This appeared to be universal, and must, I suppose, have arisen from the yielding of the Brinjarri kurries on the ribs. I believe that the arches in the first series separated more

than any of the others; but even here, although apparent when carefully examining the face of the arch, and the courses of brick of which it was composed, the separation would not be recognized by an indifferent observer. Numerous experiments were made in which the relief to the centering was given both from the sides and centre simultaneously, from the centre alone, and from the sides alone. We endeavoured, in fact, to detect the method by which the material of the arch in its green or moist state might settle down uniformly, without concentrating action on any particular point. The results of all appeared to be the same, and I, therefore, conclude that these haunch separations are almost inevitable in arches built on centerings composed of materials which are compressible by the weight of the arch prior to keying. The remedy that was adopted here was the same as that described in the chapter on Bridges and figured in diagram 112.

In the arches, as I have before said, the best species of brick which was procurable from the Roorkee and Muhewur manufactories, selected for the especial purpose, and when necessary cut and squared, was used. The bricklaying was carried on with the greatest possible care under the constant supervision of the engineer in charge. Abundance of water was at hand, every mason having a tub at his elbow, and the smallest possible quantity of mortar was used. When the arch, which was commenced from each skewback towards the crown, was completed to within two courses of the keying, the sides were wedged home by the introduction of lines of planking, so that the masonry with its cement seams was tightened to the utmost; the keying courses were then applied with the hardest brick driven in with mallets.

The centering was lowered early on the morning after

the arch was keyed; and immediately the ribs were removed, or seven or eight days afterwards, each arch was examined and its settlement recorded in a table. (*vide* volume of tables, Appendix P). The actual depression of each arch at the number of points noted in the diagram was shown by referring to a fixed bench-mark on the work, and entirely detached from the arches.

An abstract from the table above referred to shows that the following mean depressions resulted on the removal of the centerings of the different arches ;—

Number of Arch.	Mean Depression.		Number of Arch.	Mean Depression.	
	Haunches.	Crown.		Haunches.	Crown.
	Feet.	Feet.		Feet.	Feet.
1	0·1005	0·1905*	16	0·0990	0·1875
2	0·0955	0·1940	17	0·0880	0·1975
3	0·1605	0·2710	18	0·1060	0·2335
4	0·0932	0·1785	19	0·0832	0·1325
5	0·1135	0·1950	20	0·0265	0·1135
6	0·1552	0·2475	21	0·0272	0·1155
7	0·2115	0·3180	22	0·0457	0·1355
8	0·0965	0·1650	23	0·0873	0·1509
9	0·0870	0·1445	24	0·0837	0·1460
10	0·0895	0·1895	25	0·0620	0·1060
11	0·1029	0·1987	26	0·1067	0·1708
12	0·0760	0·1290	27	0·0620	0·1340
13	0·0502	0·1290	28	0·0790	0·1550
14	0·0765	0·1419	29	0·0601	0·1335
15	0·0832	0·1530	30	0·0485	0·1305

The arches were not allowed to be touched by superstructure until a period of six months had elapsed from the date of their being keyed.

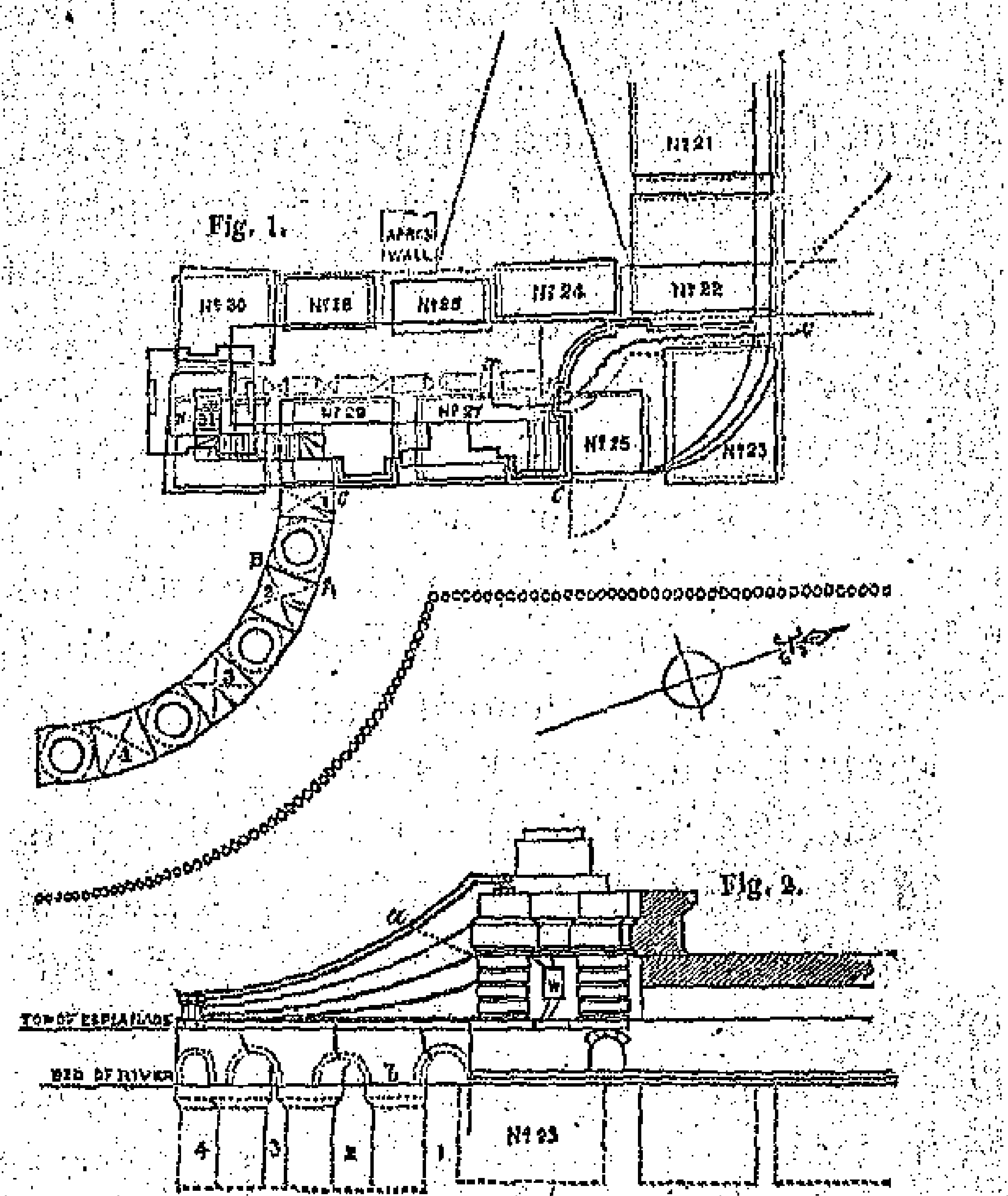
During the construction of the arches, which, it will be understood from diagram 158, was carried progressively from No. 1 to No. 30, the spandril walls with their superflooring advanced with an equal regularity of progression; the one being six months in advance of the

other. Immediately the flooring was completed across the aqueduct from one abutment to the other, the railroads which I have previously described as having been gradually worked inwards, from Muhowur on the north and from Roorkee on the south, were connected by a line laid upon the flooring. At this period, therefore, we had a high line of railroad running on the level of the canal bed from the Peeran Kulleeur digging and the Muhowur brick manufactories, to those at Roorkee, together with a single line, which, on the lower levels of the cutwater heads, was connected to the upper ones by inclined planes. The latter was at this period of progress a very convenient siding for waggons used in the carriage of material.

The probability of settlement occurring during the raising of the superstructure was naturally a circumstance of considerable anxiety. On such an extended area of foundations, connected with soils of various descriptions, it was hardly to be expected that we should entirely escape from a contingency which, although not likely to be of serious importance, might lead to disarrangements even during the progress of construction. In the plan of separating the building into two masses, and the canal waterway into two channels, we had as far as they were concerned anticipated the probabilities of settlement; we were, therefore, not totally unprepared for its occurrence. Early in 1852, when the right abutment had been loaded with the first series of arches, a crack quite independent of the main body of the building showed itself longitudinally through the wing which is marked as No. 1, in diagram 158. This crack commenced on the arch of the waste channel which was connected with the interior of the wing. It ran back about half way through the building, terminating on the escape channel arch which was situated nearest to it. The direction of

the crack is shown by the line x x in the accompanying diagram:—

Diagram 155.



On the line taken up by the crack, the masonry, both in sub- and super- structure, was clearly the weakest. Beyond the points x no signs of dislocation existed; the wing superstructure, however, in the neighbourhood of the window w, showed hair cracks, as are represented in fig. 2. At the same time a slight settlement took place in the adjoining quadrant, or terminating revetment of the embankments, on which the steps connecting the high and low levels were in progress of building. I have marked in fig. 2 the position of the cracks which showed themselves on this portion of the building. On the front of the wing c c no trace of any sort of disarrangement

could be detected, but there were certain appearances on the flooring of the water channel in immediate connection with the crack that led me to imagine that the whole front on *x, c, c*, together with the quadrant itself, had slightly settled forward, that is to say, that the mass of building on that side had separated itself from the main body of the aqueduct. It appeared to me that the blocks numbered 22 and 23 had settled down towards the front, as the flooring on their side next to the crack *x* was slightly elevated. The settlement, however, was so exceedingly slight that the use of the plumb-line was insufficient to detect any deviation from the perpendicular. In fact, the flooring at *x* on the block side being somewhat raised or heeled up, seemed to be conclusive that the settlement had taken place on the side towards the foot of the building *c c*. The blocks Nos. 23 and 25 had merely the weight of the esplanade and the angle of the building upon them, and this weight would not alone, I imagine, have led to the settlement.

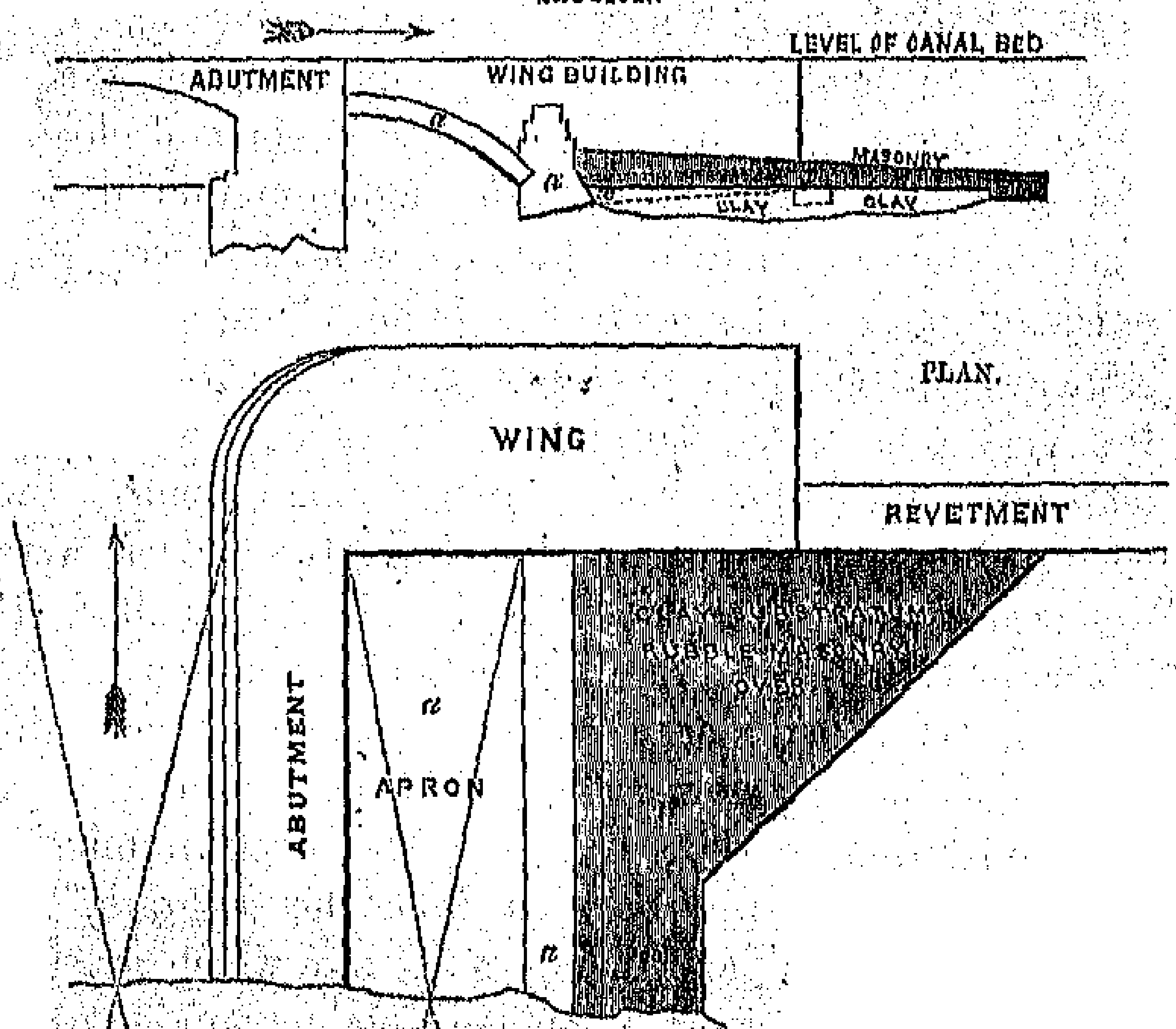
The quadrant wall foundations were originally designed by me in blocks similar to those on the body of the aqueduct. Economy led me to adopt circular wells, as shown in the diagram. Upon these circular wells the superstructure undoubtedly presses irregularly, that is to say, the vertical pressure of that portion of the masonry forming the segment of a circle of which the line tangential to two wells is the chord, falls beyond the foundations. Whether this can be admitted as an evil sufficient to lead to irregularity of settlement, I am not prepared to say, although, from the tenacity of the masonry, and from the compactness of form with which it is put together, I should very much doubt it. At the period, however, when these defects were observed, the quadrant

especially was in a very unprotected state. Its convex front was laid bare to a great depth to admit of the front apron being built, and earth had been by some oversight or other thrown upon the concave side. There appeared to me in either case, whether in that of the wing or in that of the quadrant, to be no doubt whatever that a slight settlement had taken place to the wells and blocks. The position of and the abrupt determination of the crack on the wing, left the whole question, however, very much in doubt. The point was inquired into, and the state of the building was most carefully examined by the engineers, both European and native, who were employed, and who, from having superintended the construction and sinking of the blocks themselves, were well acquainted with the work in all its details. It is possible that, had the foundations consisted of an uniform series extending over the whole surface, the weight of the superstructure would have had a more equable bearing upon the blocks. The blocks numbered 24, 26, 27, as it will be seen from the diagram, are comparatively small, and, being of the size which practice showed to be the most unmanageable in sinking, had become considerably disarranged, especially No. 26, which had got altogether out of the line. Nos. 24 and 26 were covered by the apron which I have described and figured in diagram 150. This part of the wing, therefore, which would otherwise have been in direct connection with the canal channel, was well and efficiently covered. In advance, however, Nos. 28 and 30 were exposed. I, therefore, to protect this exposed point, and at the same time to strengthen the wings as much as possible on the canal side, carried into immediate effect the construction of a further guard or protective apron against the action of the water in the canal channel when in contact with

the wings. The work done at this time will be understood from the following diagram:—

Diagram 156.

SECTION.

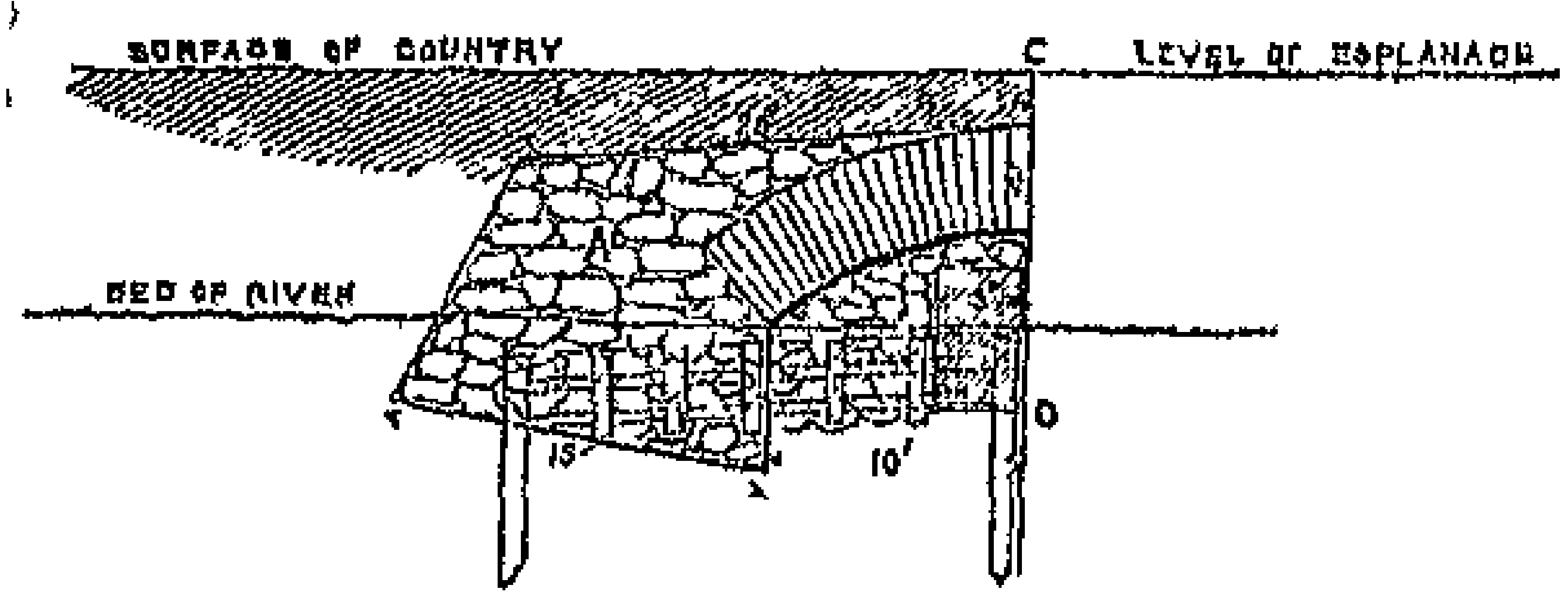


The above shows a section across the aqueduct abutment and apron *a a*, over which the canal current passes in approach to and departure from the masonry building. *a a* shows a continuation of the apron *a a*, which was designed at the same time, but which was omitted as an expensive appendage, and under the idea that it might be dispensed with. The action, however, of the settlement above described rendered it indispensable that no protective means should be left unresorted to for adding strength and watertightness to this part of the structure. Instead, therefore, of following out the original design of extending the apron, as shown by the dots in fig. 1, I

laid down a stratum of the best clay procurable, at the angle near the wings, giving a covering of rubble masonry, so as to prevent any probability of the downward action of water affecting it. The shaded portion of the above diagram will show in section and plan the work that has been done. Its main object was to prevent the water which stands on the high levels from acting injuriously by downward pressure upon the floorings of the wing buildings.

As far as the above went, very great additional security had been given to the canal channel side of the wing buildings. I had now to advert to the opposite or country side, where, as in the case of No. 1 wing, a settlement forward was to be guarded against. The front of all this work was in process of being piled and protected by boxes filled with heavy material. A few of the piles had been driven, and these piles came into use as adding strength to the work which I proposed to substitute for the boxwork on the wings. The new species of protection will be shown by the following diagram, the boxwork apron as originally planned being represented by dots :—

Diagram 157.



The large quantity of broken or vitrified brick and refuse material which was collected at the brick-fields and in the neighbourhood of the works, enabled me to carry on this with great facility, and comparatively with great

cheapness. Lines of 3 foot cubes built of rubble masonry were laid in contact with and along the whole line of wing and quadrant, and as much material of this description as could be obtained was added, so as to give weight and solidity to the whole. Over this, a masonry apron in the form above described was thrown, the arch bearing with its full weight on the front C C, and upon the convex face of the quadrant. This arch rested on a very massive abutment A, built of rubble work, which was allowed to dry before the arch was constructed. It will be seen by the shaded parts of the above diagram, that the whole of this protective apron is covered by the turfed esplanade which meets that of the masonry wing. With the exception of iron bonds which were used when raising the superstructure of the wing above the level to which it had reached before the cracks were observed, no other measures were taken ; and it is supposed that what has been done will place the building out of the reach of further disarrangement. To counteract any irregularity in the sinking of the wells upon which the quadrants are built and (what appeared to me not at all unlikely) the probability of the sinking of the superstructure of that portion of the building affecting the wing itself, the quadrant is, although carried up to the wing wall, and in the closest contact with it, built entirely separate, that is to say, between the wing and the quadrant there is no bond in the brickwork. By this arrangement, action of settlement on the quadrant will affect that part of the work alone, and not involve in its disarrangement that of the wing.

A short time after the fifth series of arches were relieved from their centerings, a slight settlement (of the substructure I imagine) of that part of the building must have taken place. The action was shown by the arches coming in contact with those of No. 4 series on the

down-stream side, whereas they had been built half an inch separate. Not the smallest trace, however, of crack could be discovered, nor did the most strict examination of the piers by the plumb-line give any clue to the disarrangement. The water, however, which was standing on the floorings, and which rested on the steps at the foot of the piers, showed a slight difference of level at the opposite ends of the structure. Such small differences are barely appreciable, although this, with the fact of the arches of the No. 5 series coming in contact, although they were built separate, proves that there was settlement somewhere or other.

It would appear that, in defiance of the arrangements that were made for converting the bays lying intermediate between the different series into abutments, the plan and section of which are shown in diagram 153, p. 494 of this volume, a slight action was exerted by the thrust of the arch upon the piers in immediate connection with the abutment bays. In stating that such was the case, however, I confess that such small differences as I am about to record must be accepted with some doubt as proofs of such action, when the perpendicular surfaces upon which the plumb-line was used consists of plain brickwork. I consider it necessary, however, to state the results as reported by the executive engineer, whose interest in them was naturally very great, from the circumstance of his having suggested the expedient and superintended the whole up to its completion. The first notice that reached me on the subject was alluded to in my annual inspection report, dated 11th May, 1852. Since the arches have been completed, and the centering and abutment bays have been cleared out, I have had the whole of the piers carefully examined with the plumb-line, and the results are shown by the following table :—

—	Deviations from Perpendicular.			
	At 5 feet from up-stream face of pier.	At 5 feet from centre of pier up-stream.	At 5 feet from centre of pier down-stream.	At 5 feet from down-stream end of pier.
	Inches.	Inches.	Inches.	Inches.
Right Abutment	$\frac{1}{4}$	—	—	—
No. 1 Pier . .	$\frac{1}{8}$	...	...	$\frac{1}{8}$
" 2 " . .	$\frac{3}{8}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
" 3 " . .	—	—	—	—
" 4 " . .	...	...	$\frac{1}{8}$	$\frac{1}{8}$
" 5 " . .	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$
" 6 " . .	—	—	—	—
" 7 " . .	$\frac{1}{8}$	$\frac{1}{8}$	—	—
" 8 " . .	$\frac{1}{4}$	$\frac{1}{16}$	...	$\frac{1}{8}$
" 9 " . .	...	$\frac{1}{16}$	...	$\frac{1}{8}$
" 10 " . .	$\frac{1}{16}$	...	...	$\frac{1}{8}$
" 11 " . .	...	...	...	$\frac{3}{8}$
" 12 " . .	$\frac{1}{8}$	...	...	$\frac{1}{8}$
" 13 " . .	...	...	$\frac{1}{8}$	—
" 14 " . .	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	—
Left Abutment .	...	...	...	$\frac{1}{8}$

It will be evident that such small differences can have no effect upon the building, but they are (if dependent on the action of the thrust of the arch) of exceeding interest, as showing the effect of thrust upon abutments, and the enormous power that must have been exerted in the present case to have acted in the smallest degree on such immense masses. The separation of the courses of brick at the haunches must not be confused with the action to which I am alluding. This separation took place during the progress of the building of the arch, frequently when it had reached to 5 feet, sometimes more, from the impost block, and was clearly dependent on the giving either of the ribs and support of the centering itself, or of the kurries, and material upon which the intrados rested.

The above gives in detail the whole of the difficulties that we had to contend against during the period of our

operations, the main body of the building having, in fact, suffered nothing from settlement; that on the No. 1 and No. 3 wings being confined entirely to the wings themselves.

The floorings and spandrils were entirely completed by the end of March, 1854, and the remaining work, which consisted of raising the side and centre walls, completing the wings, and making the ogee curves connecting the aqueduct proper with the earthen aqueduct revetment, was completed without any difficulty. The design of all this part of the work will be understood from the sheets of plans in the Atlas.

The only part of the superstructure that requires especial explanation is the method which I have proposed for laying the chambers dry, either for purposes of examination or repair. The wing buildings were arranged internally in such a way that they may be applicable to machinery, the power for which is also arranged for by a series of pipes which pass vertically through the masonry of that part of the building lying in close connection with the canal channel. With these pipes, a channel running from the flanks of the chambers, with its head protected by a stone block and ring, is connected. The head of this sluice or channel is situated at that part of the aqueduct in which the expansion of width takes place. It is supposed that its use will seldom or ever be called for, and I have, consequently, avoided any application of apparatus for opening and shutting it, intending that the shutter should be removed, tompion fashion, or (if necessary from pressure of water) by a crab capstan. This channel, which is 2 feet wide by 3 feet high, is laid on a slope of 9 inches. Now, supposing it is necessary to lay one of the chambers dry. The planks are placed in the grooves at each end, and if necessary, made water-tight by the usual simple expedients. The tompions or

stone blocks are then removed by means of their iron rings; and the water which is enclosed in the chamber passes off through the channel and wing buildings into the bed of the Solani River. Each chamber has two sluices or escapes of this sort, one directed towards its upper, and one towards its lower wing. The perfect drainage of the chamber is effected by means of a cunette, or narrow channel slightly depressed below the chamber flooring, and with an incline towards the sluice head. By the means of these sluices there appears to be every facility for laying a chamber dry, whenever such may be required.

In rear of the pedestals which flank the aqueduct, and which with their superincumbent lions stand on each wing, the water-measuring apparatus, together with the steps of descent from the top of the embankment levels, to the interior of the wing rooms, are situated. The latter are covered by a block of masonry, corresponding in character with that of the pedestal itself. They lie on the side of the road of communication, which is kept free and open. It is on this road that a single line of railroad is fixed, passing above the top of the flank walls of the aqueduct. It continues in prolongation along the top of the embankments. On the left embankment, this line of railroad will connect the interior of the workshops' yard with the works at Dhunowri. On the right a similar line will extend from the Roorkee Bridge to some fixed and convenient point beyond the Muhowur Bridge. The great object of both these lines of railroad is to establish a rapid means of communication, so as to provide the utmost facilities for the passage of waggons; in the first place, for repairs of embankments; and in the second, for the carriage of stores and other purposes. It is chiefly, however, for the purpose of carriage of earth for repairs of the aqueduct embankments that these railroads were

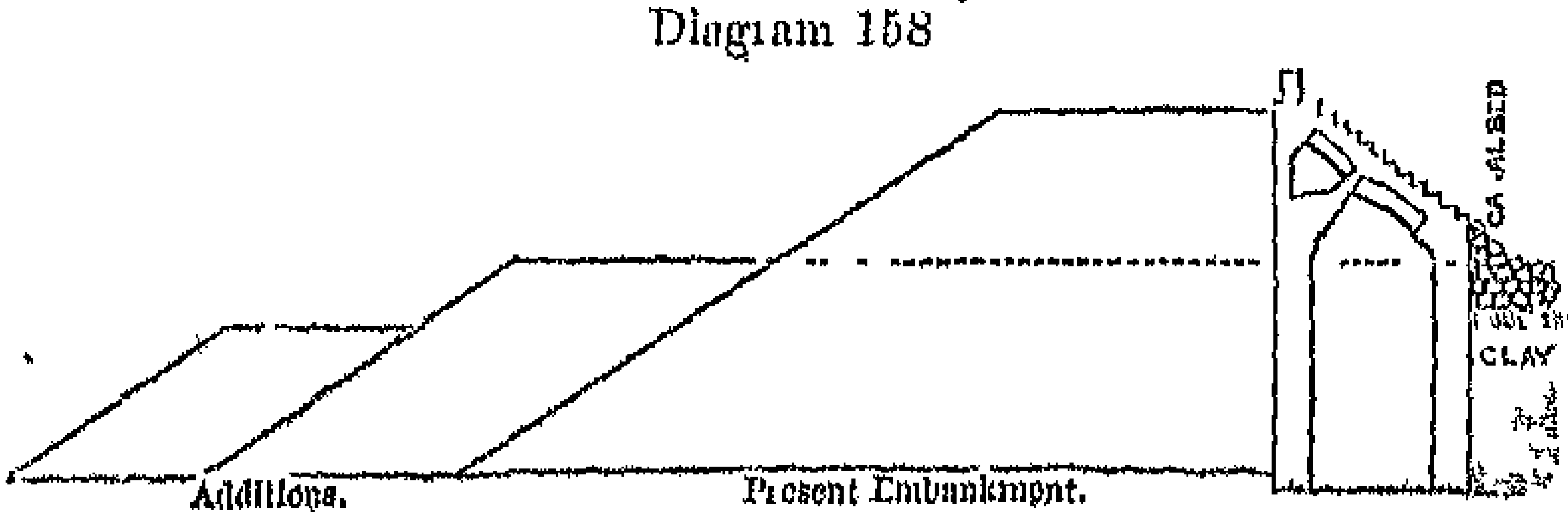
devised; and that they should be maintained in perfect order for this especial purpose, is a point of such importance, as regards the security of the aqueduct works, that no time nor labour should be spared in securing their efficiency.

Here, therefore, the question of establishment for the maintenance of these extensive embankments arises. In considering the details, it must be recollected that the whole of the earth required must be brought from the sides of the valley towards the centre. From the particular circumstances, in fact, in which the Roorkee workshops and other buildings are situated with regard to the aqueduct, it appears to me, that earth can only be procured from Muhewur.

I consider it to be a law that no further excavations are to be made on the surface of the valley at the foot and outside of the embankments. My views at present are strongly opposed to any measures leading to outside excavations. Those which have been already done cannot be undone. They were convenient at the early part of our operations, and by smoothing off and sloping the ground in their neighbourhood they are at present no very great eyesore. There can be no doubt, however, that the removal of the supersoil at this particular point, and by so doing, increasing the difference between the water level in the canal and the surface of the valley, demands a remedy. We have established low patches of ground, the perfect drainage of which is difficult, although indispensable for the salubrity of the country, and for the appearance of the works. The most efficient means of drainage are offered by nature in the slopes which she has given; but it will require active measures to keep the ground in order, and to maintain it free from the rank vegetation which invariably accompanies land of this sort in the Khadir.

The state of the exterior of these embankments as explained in the foregoing paragraph appears at once to point out the propriety, if not the necessity hereafter, of protecting the external slopes, especially those in the neighbourhood of the torrent, where the embankments are very high, by a berm or series of berms, as is represented in the following diagram; raising the surface of that next to the original embankment to the height of the bed of the channel, or even higher, if such could be conveniently managed. By such an arrangement, the embankments would be strengthened to an immense degree, the contingency of leakage would be diminished to a minimum, and the evil referred to in the last paragraph would be remedied.

Diagram 158



This work might be effected by the establishment maintained for the repairs. It might be considered the stock work to be carried on at all times when the men and waggons could not be employed elsewhere. A better employment could not well be given to them. The prolongation of the steps on the exterior slopes, to meet the extent of berm above shown, would be a very simple process. In the above diagram, where there are three tiers of esplanades, the steps would merely be prolonged to meet them.

The amount of establishment proposed to be kept up for the repairs and maintenance of the aqueduct has been regulated by the number of earth waggons which it might be necessary to keep constantly at work. In cases

of emergency, daily labourers could be called into requisition, and for these occasions, spare waggons would be kept in store.

I propose that similar parties, under the same species of discipline as those which are provided for the works lying above the aqueduct, should be maintained for aqueduct purposes. There should be two of these parties, consisting of four mates and forty beldars, each divided into gangs of one mate, with ten beldars under him. These parties should have their separate charges clearly defined, one being attached to the right, and the other to the left bank.

To each party, fifteen waggons should be attached, all kept in perfect working order by periodical inspections, both of wheels and frame work. Of the above number of waggons, twelve would be in constant use; that is to say, telling off three men to each waggon, with four spare men for extra purposes: and keeping three waggons in store to replace others that might be disabled during the day's work.

Besides these fifteen waggons, which should be considered as employed on the works, I would recommend that there be fifteen others attached to each party, but remaining in store, so that on emergency, and when additional parties of daily labourers were necessary for heavy repairs, a total force of thirty waggons might be available for each embankment.

The parties might with advantage be stationed at both Roorkee and Muhewur, in equal divisions. It might be convenient also to keep the waggons at the latter place, from whence the main supplies of earth will be drawn. The buildings which now exist at Muhewur may be usefully turned to account in giving cover to this permanent establishment.

In the early period of progress I would make a

selection of twenty of the best horses that remain in the stables after the heavy works are completed, for pulling the waggons, and aiding the beldar parties; as it will be at this period, in all probability, when, from the settlement of the embankments, more work will be required than it will be afterwards. It is, in short, very desirable that from the period when water is first admitted, every care and attention should be given to the consolidation of the embankments, and this can only be effected by prompt measures for the delivery of earth at those points where settlement is observed.

The establishment, therefore, that I propose for the aqueduct is as follows:—

—	Mates.	Beldars.	Carts.	
			In use.	In store.
Right bank	4	40	15	15
Left bank	4	40	15	15
Total	8	80	30	30

with twenty horses for the use of the carts. Thus giving fifteen for thirty carts, with five spare ones.

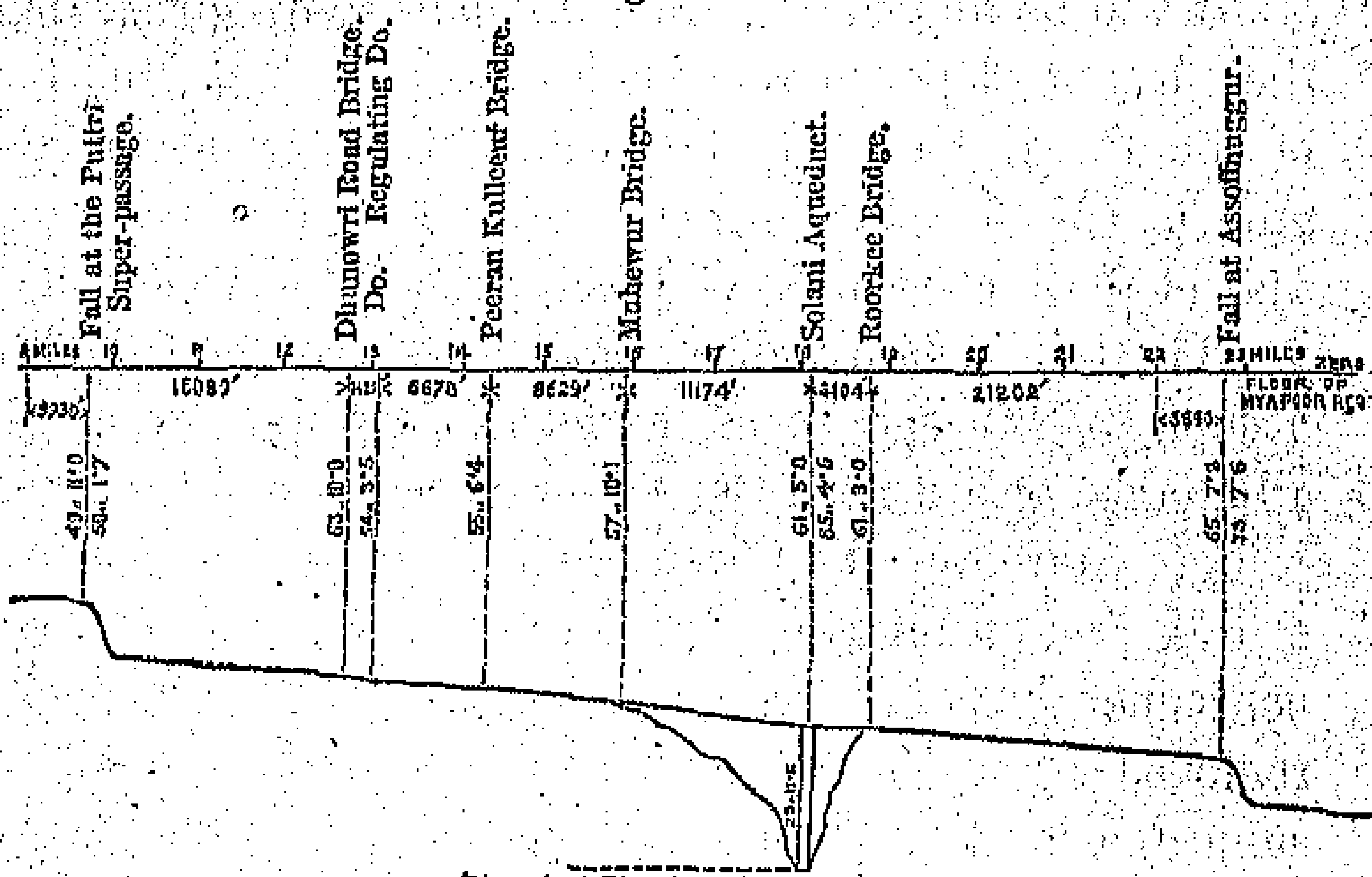
Time will show in how far this amount of establishment may be considered sufficient for the purposes required from it, and whether it may be necessary to retain the stable department, which is a troublesome and an expensive one. In the meantime, however, I am satisfied that it would be unwise to trust the aqueduct works to smaller parties. Much requires to be done independently of mere consolidation. The completion of the slope turfing, the drainage, and proper adjustment of the ground on the outside of the aqueduct, with prompt remedial measures when cutting and disarrangement of earth take place during rains, are points which, if looked after in the few first years of progress, will, in all probability, prevent trouble afterwards.

On the aqueduct itself I have only a few words to say further, viz., that the preservation of the earth embankments from trees and jungle, and, if possible, the riddance of all vegetation excepting *Doob* grass, which ought to cover the whole of the slopes, and at least 3 feet in width of the upper flat in connection with them, appears to me to be very desirable, not only for the purpose of preservation, but for the general appearance of the work.

The masonry aqueduct will be stuccoed at some *future period*, when the effect of the water passing over it has been well shown, and when other more important avocations do not interfere with its progress.

The levels of the canal bed, as connected with the aqueduct, are the most important part of the whole design. They and the works connected with them have been most anxiously considered, and from first to last have been the centre to which all my thoughts have radiated.

Diagram 159.



The above section of the canal bed from the tail of the Puttri Falls and super-passage to the head of the Assoffnuggur Falls, is the best introduction to this subject:

I may explain that on the whole line of aqueduct the tops of the embankments are laid down on a slope of 1·5 feet per mile, and the masonry revetments and other work appertaining thereunto are adjusted to this particular slope. The canal bed, however, is on a slope of 1·25 feet per mile, so that above the up-stream end of the aqueduct, or at a distance of three miles from the Roorkee Bridge, the esplanade is 9 inches higher than it is at Roorkee.

Referring to the section above given, it will be observed, 1st, that the slope of the canal bed from the tail chamber of the Puttri Falls to the flooring of the Roorkee Bridge is equal to 1·25* feet per mile; 2ndly, that the slope of the canal bed from the flooring of the Roorkee Bridge to the sill or waste-board of the Assoffnuggur Falls is equal to 1·096′ per mile; and 3rdly, that the flooring of the aqueduct is laid on a level† with that of the Roorkee Bridge.

It will be understood, from the data above given, that the effective slope on the whole line, viz., from the tail of the Puttri Falls, to the head of those at Assoffnuggur, is (65 feet 7·8 inches) – (50 feet 1·7 inches) = 15 feet 6·1 inches in 68,600 feet, or 1·193 feet per mile.

The tail curtain wall of the Roorkee Bridge is laid to a depth of 20 feet, so as, as far as possible, to preclude all chance of evil from the action of retrogression. This bridge, moreover, has been made the point on which a change from a high to a low level has been effected, and consequently, has become in a greater or less degree removed from the effects of retrogression. It will be subjected in all probability to deposits. The tendency of the low levels from Roorkee to Assoffnuggur is to throw back water upon the aqueduct channel, to modify the

* Actually 1·2875 by proof levels.

† Actually 2 inches lower by proof levels.

declivity of bed, and to save the latter from some amount of attrition.

The aqueduct flooring, which (*vide* section, diagram 149) is situated at a distance of 3,404 feet from that of the Roorkee Bridge, is, I have shown, placed on a level with it. The object of so doing in this case was similar to that before described, where the raising of the sill of the Assoffnuggur Falls had a tendency to throw a deposit on the flooring of the Roorkee Bridge, which lies on its up-stream side. Here the position of the aqueduct flooring renders it liable to deposits from that of the Roorkee Bridge, so that what with the floorings of both the falls and the bridge, the aqueduct is not only protected to a certain extent from retrogression of levels, but there is a tendency to the formation of deposits over its whole surface.

The true slope of the canal bed from the Muhowur to the Roorkee Bridge, intermediately with which the aqueduct is situated, is 1·25* feet per mile. The flooring of the aqueduct, therefore, which is situated 3,404 feet above the bridge, ought to have been raised ·8 foot† above it, instead of being on one level, had uniformity of slope on the whole line been determined on. There was a great object, however, in depressing the flooring of the aqueduct, so as to remove the action of water in ingress and egress as far as possible from the masonry; in fact, to deprive the water, if such could be done, of all action, and to secure a steady and easy flow over the work.

How far the arrangements that I have devised will answer remains to be seen; whether there is any advantage in keeping the aqueduct flooring depressed, remains to be proved. The whole object of the first has been

* Actually 1·2345 by proof levels.
† Actually 0·796 by proof levels.

to protect the line of raised embankment from the effects of current, and to reduce, as far as I could, the action of the water in passing from masonry to earthwork. That of the second is closely connected with the same object; but if results should show the necessity for raising the flooring of the aqueduct to the height demanded by the effective slope, the remedy is an easy one, and the addition of the required layer of masonry may be combined with measures for securing water-tightness by the intervention of asphalte or any other impervious substance suited to the purpose.

The following tables will show the amount of water discharged through the earthen aqueduct channel, as well as that which the masonry channels of the aqueduct proper are capable of carrying at different heights or depths as noted in the first column. The velocity being estimated at that due to the effective slope of the canal channel from the flooring of the Puttri Falls to the sill of those at Assoffnuggur, this being:—

Table I.—Earthen or Revetted Aqueduct.

D.	R.	Velocity.			Area.	Discharge per Second.
		V.	u.	U.		
1	11·83	1·28	2·37	0·19	150·0	192·000
2	23·40	1·82	3·17	0·47	300·0	546·000
3	34·59	2·22	3·76	0·68	450·0	990·000
4	45·57	2·55	4·20	0·90	600·0	1,530·000
5	55·46	2·82	4·58	1·06	750·4	2,116·180
6	65·07	3·06	4·88	1·24	903·7	2,765·320
7	74·33	3·27	5·15	1·39	1,060·0	3,466·200
8	82·36	3·45	5·43	1·57	1,219·5	4,207·275
9	91·12	3·62	5·62	1·62	1,382·0	5,002·840
10	99·67	3·79	5·86	1·72	1,548·0	5,866·920
11	106·72	3·93	6·05	1·81	1,716·5	6,545·845
12	114·84	4·08	6·20	1·96	1,888·5	7,705·080

Table II.—AQUEDUCT PROPER—MASONRY CHANNEL.

D.	R.	Velocity.			Area.	Discharge per Second.	
		V.	u.	U.		One Chamber.	Both Chambers.
1	11·735	1·28	2·37	0·19	82·080	105·0624	310·1248
2	23·102	1·81	3·17	0·45	166·248	300·9088	601·8176
3	34·081	2·20	3·72	0·68	251·137	552·5011	1,105·0028
4	44·608	2·53	4·20	0·86	336·137	850·4266	1,700·8532
5	54·678	2·80	4·54	1·06	421·137	1,179·1836	2,358·3672
6	64·323	3·04	4·88	1·20	506·137	1,538·6565	3,077·3130
7	73·567	3·25	5·20	1·30	591·137	1,921·1953	3,842·3906
8	81·622	3·43	5·38	1·48	676·137	2,319·1499	4,638·2998
9	90·447	3·61	5·62	1·60	760·704	2,746·1344	5,492·2688
10	98·643	3·77	5·86	1·68	844·616	3,184·2023	6,368·4046
11	104·430	3·88	5·95	1·81	927·463	3,598·5561	7,197·1128
12	111·661	4·02	6·15	1·89	1,009·463	4,058·0413	8,116·0826

We now come to the bed of the Solani River itself, and the works that have been designed and executed, first, for the direction of its course upon the waterways, and, secondly, for retaining the torrent upon this course afterwards. This brings us to

III.—BUNDS AND EMBANKMENTS ON THE SOLANI RIVER, IN CONNECTION WITH THE AQUEDUCT.

From what has been said before, it will be understood that the foundations of the aqueduct building, in addition to the line of blocks which was substituted for that of piling as originally planned, have, *both in front and rear* of the floorings, curtains and aprons, consisting of frame boxes filled with heavy material, and covered with lines of piling. By referring to the plan in the Atlas, it will be seen that the flanks, both on the up and down stream side, have been protected by works of similar character, somewhat different in disposition, but tending to protect the building from any injurious action from the *current in its* passage through the

waterways. The aqueduct building itself, therefore, as well as its immediate neighbourhood, has been strongly protected; and as far as those protective expedients have been carried, they appear to be in every way efficient.

From the character of the mountain torrents with which the canals come in contact in the upper part of the Doab, it will not be overlooked that the *bed* of the Solani undergoes constant change of direction, every flood cutting from one side the soil that is delivered elsewhere on the other; and that here, also, as elsewhere, nature appears to have designed for its use a wide and extensive valley or khadir, by the borders of which the vagaries of the torrent are limited.

By referring to Plate XXVII. Sheet 17, Atlas, it will be observed that the bearing of the aqueduct across the valley from Muhewur to Roorkee is laid at an acute angle with that of the bed of the river, so that the course of the river came in awkward contact with the left abutment of the work. This evil led to the inconvenience as well as to the accident that I have before described as having happened to the left wing during the floods of 1850, at a period before the revetments and walls were completed. The remedy could not be applied until the waterways on the right were sufficiently advanced to admit of the course of the river being altered; and it was not until the cold weather of 1850–51, or that immediately succeeding the rains, when the above interruption took place, that we were able to commence the works in the valley for this purpose.

A reference to the sheet above referred to will explain the steps that were taken for the purpose, better, perhaps, than any description that I can give otherwise. Our object was to bring the course of the torrent fairly and directly upon the waterways, and to get rid of the old

bed, the inclination of which was towards our embankments, and obliquely upon the piers of the aqueduct. A series of levels having been taken, so as to show the contour of the land in immediate connection with that to be operated upon, I carried a line, in prolongation of the longitudinal axis of the right bay, up stream, until it met a curve of the river, as shown in the map. The distance between the aqueduct and the meeting of the curve by the line in prolongation was 9,400 feet. On this alignement the new course of the river was to be directed. In designing this I preferred a series of numerous small channels, as at *a, b, c, d, e, f, g,* to one or two large ones, as by multiplying the channels the surface of soil to be acted upon by the current was greatly increased, and it was by the action of the current that I proposed to gain a channel sufficiently large for the passage of the water. The work done here consisted in excavating five parallel trenches of 50 feet width each, in prolongation of the abutment and piers; their position being figured in Plate XXVII., Sheets 17 and 18, of the Atlas.

The slopes of the bed of the new cuts were to be uniform; commencing from the upper bed at B, and terminating on the aqueduct. The slope was, in fact, 1·276 feet per 1,000 feet, from a point on the cutwaters of the Solani Aqueduct, one foot above the flooring.

The excavated earth from the channels *a, b, c, d,* was thrown on the right; that from the channel *e*, on the left.

The two channels *f, g,* for the passage of the Imli Nulla into the channel *e*, were each 50 feet in width, with a space intervening of 70 feet in width. The earth excavated from *f* being thrown on the right, that from *g* on the left bank.

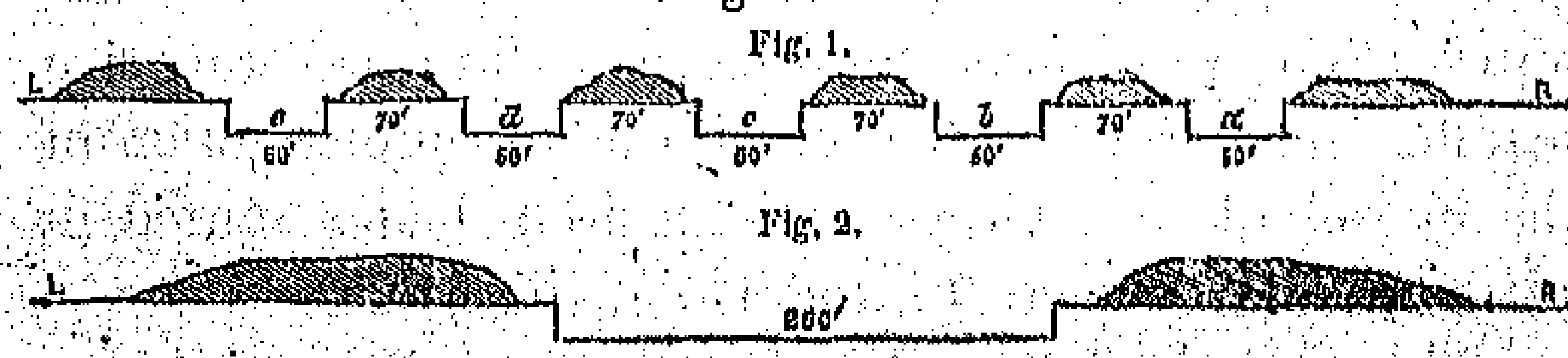
The bunds, which are described in the plan at right angles to the cuts, and to the current that was to pass

down them, were made from sand or soil thrown up from the front of each.

The levels were determined by points which were fixed on the contour. These, together with the orders which were given on handing over the work to the executive engineer, will be seen on the face of Plate XXVII., Sheet No. 17, of the Atlas.

The transverse section of these five cuts compared with that of a single channel with equal waterway, will show the advantage that the former has over the latter where wear and tear is the object to be gained; it is a very good elucidation of the value, also, of that element in the formula for discharges through pipes and channels, consisting of the accurate measurement of the wall, or of the perimeter in contact with the fluid.

Diagram 160.



Here, in comparing the value of the wall or surface to be acted upon, in the figures above given (supposing for simplicity's sake that the depths are 10 feet), we have in the first case, $70 \times 5 = 350$; and in the second 270 only, the discharge in the first case, supposing that the walls of the channel were rigid, being proportionately less than that in the second. The action of the fluid, however, on the smaller channels (which would in the above case reduce the amount of discharge), here tends to enlarge and widen the channel, and thereby to gain the object which is desired.

Economy largely enters into the plan which has been adopted, not only in reducing the extent of excavated channel, but in rendering that excavation more easy, by

shortening the distance to which the earth has to be carried.

The action of the floods during the rains of 1851, which was the *first rainy season* in which the torrents were passed down the cuts, and between the abutments of the aqueduct, was comparatively slight; the cuts, however, did their duty, and the bunds entirely removed the river from its old course. During this rainy season, the piers and floorings of the aqueduct, and the piers placed intermediately for the support of the railway, were in progress.

The first flood was a very early one, and came rather unexpectedly at 4 P.M. on the evening of the 14th June; the 20th of that month being usually considered the time up to which the works were tolerably safe from floods. The five cuts were, however, completed, with the exception of small bars across two of them left until the last moment for the purpose of cross-communication. The torrent came down through the cuts, leaving the old bed of the river high and dry, and not interfering with the bunds in any way. The water of this flood rose 4 feet above the flooring of the aqueduct.

On the 9th of July, a flood 3·75 feet in depth on the flooring passed off without doing any damage, although showing an inclination to cut on the right, upon which the current had made a set. The executive engineer, therefore, stopped up the heads of the two cuts, *a* and *b*, as well as the two right waterways of the aqueduct. During this flood, it was supposed that at least four-fifths of the volume passed down the above two cuts. The bunds, which were made, were raised merely above the surface of the ground, so that they might be topped by water rising above 6 feet. It must be understood that at this period the flank protections to the abutments on the river side had not been built, and that it was

of the utmost importance that those parts of the work should be removed from all danger.

The up-stream piers, both of the main aqueduct and for the support of the railway on the up-stream face, were at this time completed. On the 10th of July, and in reporting the above flood, it was stated, that "our cross-communication with the two banks is now complete for foot passengers, and the railway will, in a few days, be laid from abutment to abutment. The work remaining, however, to complete the piers on the down-stream half of the aqueduct ready for arching, is very considerable."

The state of the five cuts after the above two floods was not much changed. The edges of the two right ones had become serrated or broken into ravines. In some places the earth had fallen in 10 feet from the original digging; but the average was not more than 4 or 5 feet, and at many points the banks were hardly cut away at all.

On the 14th of July, a flood 4¼ feet above the aqueduct flooring passed down the river. The two right cuts having been bunded up at their heads, all the water came down the three others, *c*, *d*, *e*. Although the two right waterways of the aqueduct were bunded, not the slightest action was observable on the right abutment. This flood was not sufficiently high to test the measures that had been taken, but the results, as far as they showed themselves, were satisfactory.

During this flood, work was carried on as usual on the superstructure, although water was flowing through the eleven centre arches.

The effect of turning the river from its old course appeared at this time to influence the movement of the current above the head of the cuts at the point B. The stream began to abandon the turn or deep loop on the right bank above the cuts and to come perpendicularly

down on the alignement of the centre channel. We found it, therefore, desirable to ease off the sides of the cuts in places where the natural soil would not give way, as this supersoil acted as a most perfect check to abrasion, which instantly took place on its removal.

On the 22nd of July, a 6 feet flood passed down without causing any inconvenience, and was as easily disposed of as the former ones. The effect of this flood placed at rest any doubt about the efficiency of our cuts and bunds. The water passed down three of the cuts at the head, and broke through the bund at the head of cut *b*, not owing to its having topped the bund, but to the action of the current on its face.

Up to the termination of the rainy season of 1851, very little rain had fallen about Roorkee itself. The Solani floods originated entirely from falls of rain in the Sewaliks. The results of our works, however, were very satisfactory, especially the inlet of the Imli Nulla, with its bunds, at and in connection with which I had anticipated much trouble.

Previously to the setting in of the rains of 1852, the series of arches marked in diagram 153 as 1, 2, and 3, had been completed, and the 4th was in progress during the months of June and July. On the 9th of August, or on the day of completion of the No. 12 Bay, the whole of the down-stream half of the aqueduct was arched in. We at this time, therefore, began a new period in which the floods had to act on the work with the down-stream half loaded with arches, and the up-stream piers and railroad supports acting as obstructions to the current.

As in the season of 1851, the floods were earlier than usual. A small one came down the river on the 15th of June, without doing damage of any great importance, although it reached the works when the bunds were under repair. On the 27th of June, a flood of seven

feet on the flooring, and on the 4th of July, one of eight feet passed through the aqueduct. These were heavier floods than we had before experienced, but they passed off without doing any damage; although at the time they were running, the two bays on the right, as well as the four on the left, connected with the arch building of the fourth series, were entirely closed. I am desirous of entering into the fullest detail on these matters, as the position of the works during this, as I may call it, initiatory period, is of much importance and interest connected with the value of the waterway of the aqueduct. For instance, on the flood of the 4th July there were six out of the fifteen bays closed, besides the obstruction given to the free passage of the water through the remaining nine, by the interposition in each bay of two piers for the support of the railroad.

The effects upon the bunds arising from the above floods were as follows. The main or leading bund D, situated at the head of the cuts, and which, crossing the old bed, extended some way into the country, was broken at its intersection with a hollow at a point considerably to the left of the river. As far as fracture went, this was the only bund that suffered.

The retrogression of levels which was necessarily attendant on the new cuts had acted considerably. The beds of the cuts, which were *level* with the natural soil at the point guarded by the "Nulla bund," were at this time 3 feet below their embankments; and perpendicular falls or drops had established themselves elsewhere. The same was in operation on the two cuts *f g*, connected with the Imli Nulla; the eastern one *g* being about 2 feet deeper than it was originally excavated. The western cut *f* was little affected by the floods.

On the 20th of August there was much rain, and the Solani rose to a height equal to that of the 4th of July,

or 8 feet on the aqueduct flooring. These heavy floods did great good in clearing away the remaining sand that existed in the neighbourhood of the works, from the block sinking and flooring excavation. After the flood of the 20th August, the main set of the current was straight through the centre waterway, and from thence straight against the old bank opposite the village of Mullikpoor. The deep water runs close under the bank on the opposite side to where my estate is situated.

The rains of 1852, therefore, passed away, not only without doing damage of any description, but in giving me increased confidence in the works on the Solani Valley, as well as in the sufficiency of the waterway of the aqueduct, and of the protective works connected with both its flanks and its foundations.

During 1853 the rains were by no means continuous throughout the season. In the early months there was a good deal with much interruption to work, but latterly hardly any rain fell at all. There were, however, some heavy floods, which occurred at a period when the aqueduct from having seven of its bays closed, stood a still further test of its sufficiency for all purposes required. The last arch was keyed on the 4th July, 1853, previously to which a flood came down on the 16th June, and stood $3\frac{3}{4}$ feet on the aqueduct flooring, during which the following bays (*vide* diagram 153), Nos. 4, 8 and 12 were shut. Now this was more trying than on any other occasion, from the circumstance of the centre bays of the aqueduct being interrupted. No injury, however, arose either to the bunds or to the masonry work, and the cuts became very much enlarged. The result of this year's rains was, in fact, more satisfactory than that of the years which had preceded it, and added, if anything were required to do so, to the confidence which I had already expressed of the stability of the Solani Works.

I have not attempted to describe in all their details, the different additions that were made to the bunds, &c., during the three years since the torrent was placed in its new channel. Some of the bunds originally proposed were omitted, others have been extended both in length and increased in proportions. Low ground on the right and in the vicinity of the aqueduct itself has been protected, and much improved by detached works which circumstances showed to be necessary; and the greatest attention has been given to the permanent security of the whole.

Plate XXVII. Sheets 17 and 18 of the Atlas, will show this detail, and explain the changes that have been made during the continuance of our operations, as well as the effects upon the cuts by the action of the current during the rains of 1852 and 1853.

The true slope of the bed of the Solani River as effective upon the aqueduct floorings was determined very carefully by me in 1844, by a series of levels taken on a length of ten miles, eight of which were above and two below the site upon which the work has been built. On the above length the total fall was 50·89 feet or 5·08′ per mile.

It will be understood that by the change of course, and by the straight direction upon which the new cut has been brought to bear upon the aqueduct, the natural regimen has been disarranged; and that, as I have shown elsewhere, the straight cut which brings the water upon the up-stream face has a slope of 6·787 feet per mile, an excess of slope which is uniform on the whole length of the cut on a distance of 9,070 feet. The rapidity of the slope thus given to the bed on its approach to the work, has a favourable tendency towards the establishment of deposits on the flooring of the aqueduct, and to protecting the tail from the erosion

which an uniformity of declination of bed would have led to. The effect, I imagine here, will be similar to that which I have before explained, as having arisen in all cases where the uniformity of slope is broken, and where a rapid descent delivers the water upon a slope which is insufficient to carry it forward on the same velocity with which it arrived at the point where the change of level took place. For instance, in the bed of the Solani to which our attention is now directed, we have the bed in connection with the floorings of the aqueduct similar to that shown in the following diagram,

Diagram 161.

a e b and *c d* are parallel to each other, and on a slope of 5·08 per mile, the intermediate portion, *b f c*, being on an increased declination of 6·737′.

There can be no mistake whatever in the results of this arrangement. They have, in fact, been from the period when the water was first poured down the cuts in constant progress towards completion. Rapids and abrupt descents have been establishing themselves in the bed of the cuts, with a retrogression of levels, the abraded matter being pushed forward. In other words, the shaded triangle in the above section, *e b f*, is undergoing abrasion and removal, whilst the soil so removed is thrown on the floor of the aqueduct in the triangle *f c d*. The results of the action, which I imagine to be taking place, are clearly exhibited above, where the dotted line points out the surface of the true bed of the river, as it will ultimately appear, when the water has fixed for itself a regimen dependent on the slopes which we have given to the bed.

Laying aside the fact of the great advantages derived to the work, by bringing the torrent to bear directly upon the bays, by which the protective measures for the flanks, and the discharge of the bays themselves have their fullest benefit, the foundations of the aqueduct itself derive the greatest of all possible protections from the results which I have above described, of deposits.

The slope of the river, although small when compared with that of other torrents with which we have had to deal, is still considerable. I am of opinion, nevertheless, that, from the great extent of waterway which has been given to the passage through the aqueduct, and consequently to the diminution of obstruction;—from the deposits on the flooring reducing the action of the current in its passage during floods possibly to a point lying above the masonry floorings themselves;—and from the superficial character of the river on the down-stream side, with the junction at a somewhat acute angle of the Rutmoo Torrent about four miles below it; a retrogression of levels upon the aqueduct tail is not to be anticipated. To provide against a contingency of this sort, however consecutive, lines of piles have been driven close together at a distance of 20 feet from the masonry floorings, the intermediate space being filled with box-work and heavy material, confined in its position by sleepers; an arrangement that will be understood by an inspection of the plans.

Considering the retrogression above alluded to to be improbable, I have had no hesitation in carrying out the cuttings in prolongation of the abutments on the down-stream side of the bays, so that the current may run fairly off, and not be interrupted by the turn which the old course of the river gave it immediately on its escape from the waterways. A great object that I have had

in doing this, is to keep the water at a distance from the Roorkee side of the valley, and to form the border resting on the right of the letters *a′ a′ a′* (see Plate XXVII., Nos. 17 and 18, of the Atlas), into a raised esplanade smoothed off and turfed, in continuation of that which now exists on the right of the old river. A work of this sort can be easily done by warping, and making the torrent deposit silt on the flank that requires to be raised. The improvement will be an immense one to the station of Roorkee, and can be done gradually by the aid of the establishment which must be maintained for the purposes of the aqueduct.

In estimating the theoretical, as I have already given the efficient practical value of the waterway of the aqueduct for passing off the floods of the Solani, I shall treat the subject in the same way that I have done the superpassages, *i. e.* by estimating the area of the catchment basin, which depends upon the aqueduct for its relief from drainage, under assumed falls of rain over that catchment basin.

Supposing, therefore, that 12 inches of rain fall over the whole Surface, viz., 216 square miles in 24 hours, the total quantity of water that had fallen would be—

$5{,}280^2 = 27{,}878{,}400$ cubic feet in 24 hours.
„ 1,161,600 „ in 1 hour.
„ 322·666 cubic feet in 1 second;

therefore the discharge per second would be thus :—

$$322{\cdot}666 \times 216 = 69{,}695{\cdot}856 \text{ cubic feet.}$$

I see no necessity for entering into the variety of causes that would interrupt the regularity of the above discharge, nor the probabilities of heavier falls than 12 inches in the time given; for this reason, that although the rain gauges do exhibit occasionally a greater amount of fall, even as high as 5 inches in one hour, such falls are limited to small areas, and arise in

nine cases out of ten from the breaking up of a detached mass of cloud hanging over a limited tract. As far as my experience has gone, I believe that in estimating at the rate above given, and over an area as above described, I am in excess of any actual fall of rain that has ever been recorded; and that an average fall per square mile of 322·666 cubic feet per second, as occurring upon an area of 216 square miles, is a fair and liberal allowance to provide against.

The following table explains how the above discharge will be met by the waterways of the Solani Aqueduct; the first column showing the depth of water, and the last the actual discharge through the fifteen bays of the volume due to that particular depth.

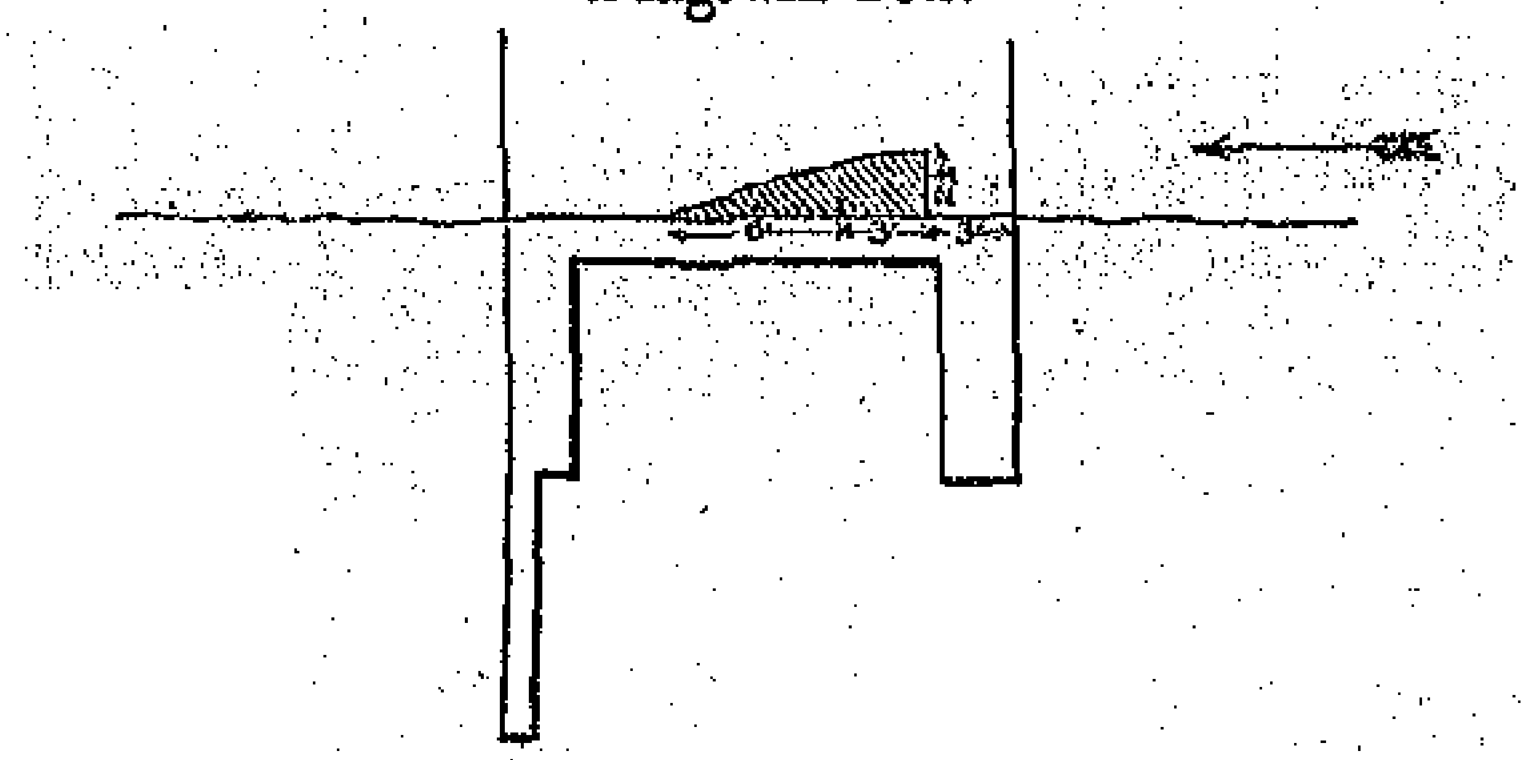
D.	R.	Velocity.			Area.	Discharge per Second.	
		V. Mean.	u. Surface.	U. Bottom		1 Opening.	15 Openings.
1·0	11·424	2·808	4·537	1·079	40·0	112·320	1,681·800
2·0	20·817	3·813	5·856	1·770	85·0	321·105	4,861·575
3·0	28·920	4·503	6·760	2·246	135·0	607·905	9,118·575
4·0	38·268	5·202	7·673	2·731	185·0	962·370	14,435·550
5·0	47·000	5·775	8·291	3·256	235·0	1,357·125	20,356·875
6·0	55·161	6·269	8·910	3·598	285·0	1,786·665	26,799·975
7·0	62·813	6·688	9·486	3·890	335·0	2,240·480	33,607·200
8·0	70·000	7·067	9·985	4·148	385·0	2,720·795	40,811·925
9·0	76·764	7·404	10·304	4·504	435·0	3,220·740	48,311·100
10·0	83·143	7·709	10·693	4·725	485·0	3,738·865	56,082·975
11·0	89·167	7·986	11·069	4·983	535·0	4,272·510	64,087·650
12·0	94·865	8·257	11·357	5·157	585·0	4,830·345	72,455·175
12·542	97·824	8·365	11·485	5·295	612·083	5,120·074	76,801·110

I have retained the slope at 5·08′ per mile, that being the natural one of the river. The modifications which have arisen from the new cut above the aqueduct, would if anything rather tend to increase the velocity than otherwise, and, consequently to increase the discharge.

It will be seen from the table that high water on the piers equal to 11½ feet in depth would give a discharge very nearly equal to that which I have estimated as a maximum, whereas the full value of the waterway which I consider to be up to the spring of the arch, or 12·542 feet above the level of the flooring, would admit of a free discharge equal in amount to 76,801·110 cubic feet per second.

In concluding this chapter, I may add, that previously to turning the water over the aqueduct, a temporary weir or overfall of 30 inches in height was raised on the flooring of the Roorkee bridge; this was built in each of the bays of brickwork, its section being as follows:—

Diagram 162.

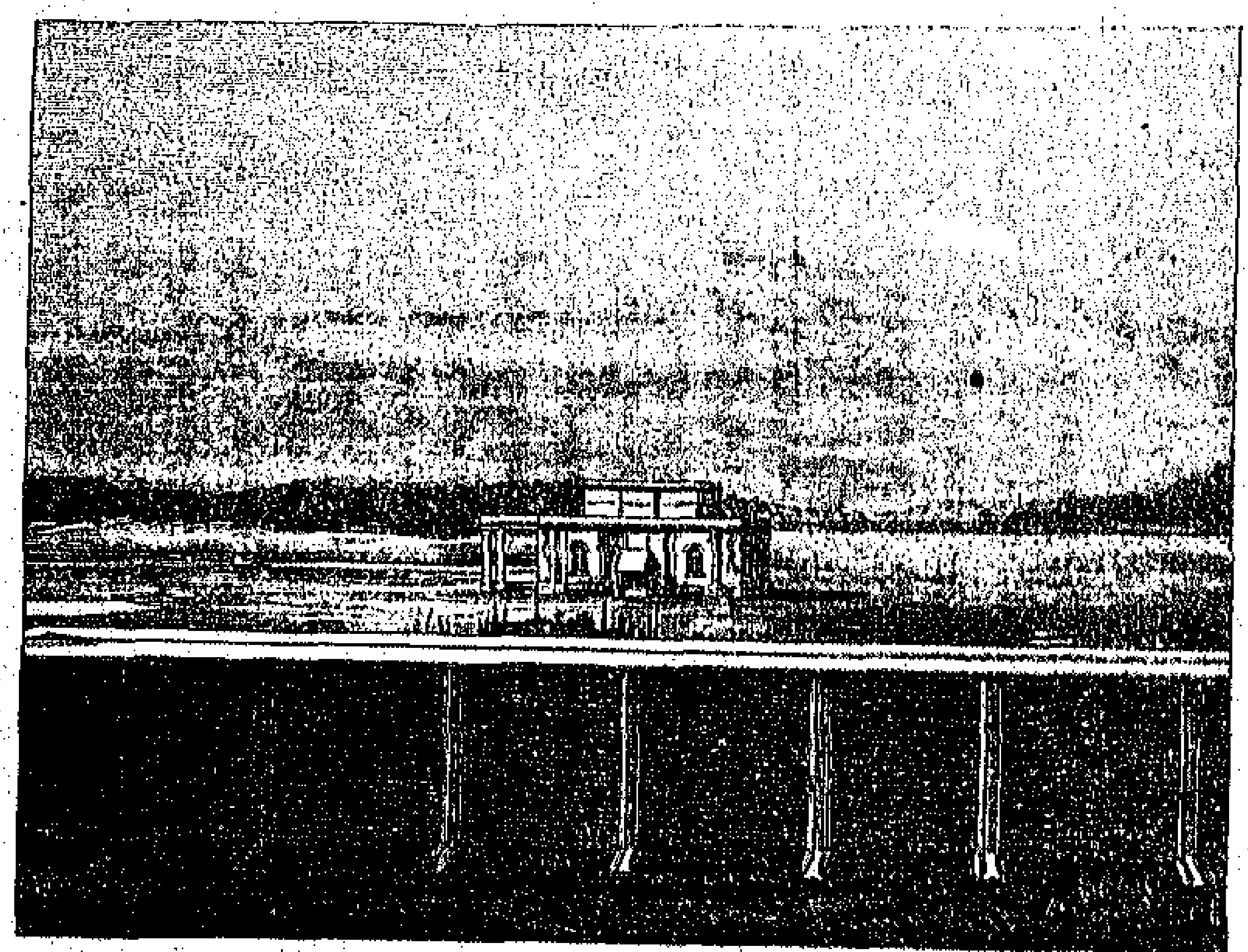


The object was to retain back water upon the aqueduct, to save the bed from wear during the early period of its being used, and to give efficient aid to consolidation. Subordinate to these it gave additional depth of water for boats, during the period when the boulder stratum was in progress of being laid down.

The bar of masonry can be removed in half an hour, or even in less time than that, should it be found to be unnecessary, or conducive to injury. It will be removed entirely when the aqueduct bed is properly adjusted.

With reference to the lower bays of the aqueduct, through which the torrent passes, it would be desirable

to see by experience whether overfalls or bars like those above mentioned, might not be built on the flank bays, or in those next to the abutments. These might be built to the height of heavy floods, say half the height of the pier, or $\frac{12\cdot457}{2} = 6\cdot228$ feet above the flooring. The advantage of these arrangements would be that they would protect the flanks, by keeping the current at a distance from the abutments in all common floods; in all, in fact, that did not exceed 6·228 feet in height. The effect would be to throw a long spit of sand of 60 feet in width on each wing, which would by no means improve the appearance. It is evident, however, that if the waterway can bear it, the proposed overfalls in the flank waterways will give a very efficient cover and protection to the abutments.



ROORKEE HOSPITAL, built by the late Captain EDW. FRASER, Bengal Engineers (killed by his men at Meerut), with the TOPE behind it.
(Taken from the roof of a house, now the Billiard-room.)

CHAPTER X.

EXCAVATION OF THE CANAL CHANNEL.

THE general design upon which a canal for irrigation is projected, has been sufficiently explained in former chapters. In this place, therefore, I shall confine myself to the method adopted for determining the capacities of the channel, and to the practical operations for excavating it. It will be understood from what has gone before, that as the trunk and its main branches are intended to act as the receivers of supply for the distribution of water over given areas, the leading point to be attended to is to place them in such an elevated position with reference to the areas to be irrigated, that there may be as little difficulty as possible in effecting this distribution. For this purpose in laying down the alignement, the watershed of the country is evidently the true position for the lines of supply. Again, for regulating the quantity of water which passes through the canal channel, the direction must be dependent on facilities for escape, and consequently on the topographical outline of the country over which it is carried. In the regions connected with the mountains it is necessary to provide for the escape of torrents, and the heavy floods to which the hilly tracts are subjected. Elsewhere it is equally desirable to obtain the aid of natural lines of drainage for receiving waste water which it may be necessary to throw

off from the canal channel. In both those cases, much care is requisite, as upon them depends the efficiency of the works as a machine for irrigation, and the health of the neighbouring population, from free and perfect drainage. It will have been seen that the Ganges Canal in its passage through the lowlands at the foot of the Sewaliks, is connected with extraordinary difficulties on the leading 19 miles of its course. On its reaching the high land of the Doab at Roorkee, its general direction lies between two rivers, the beds of which are more or less depressed below the levels upon which the canal channel is carried. It runs, as far as straight lines can run upon tortuous ones, upon the summit ridge from whence the water flows away to the natural lines of drainage. Consequently, although the flood water on the high land may occasionally be interfered with by the regularity of alignement with which the canal is laid out, the proximity of rivers lying on a lower level, offers every facility for the defect being overcome by artificial means. It is obvious that the same cause is favourable to regulating the canal by the medium of escape channels into the beds of these rivers, and that a command is obtained over the land in the tracts bordering upon them, most especially favourable to irrigation.

In table F of the Appendix, I have placed the original explanation of the method adopted by me in fixing the size of the excavated channel. This method has not been departed from in the project of 1850, although in details it has been much modified. The causes of these alterations have been before explained. In the northern or khadir tracts they depended on a change to the works connected with the mountain torrents, and are, therefore, strictly due to the engineer. In the lower or southern tracts they depended entirely on

revenue and measures for distributing the water with the greatest advantage to the agricultural community as well as to the interest of the State.

By referring to the table above alluded to, it will be observed that the design for the capacity of the channel is founded on certain axioms, by which at any given point the precise volume of water passing the canal at this point is known. This being the case, the only questions that remained to be determined, are 1st, the slope of the canal bed; and 2ndly, the depth to which the water may be carried. Both of these points are main elements in determining the capacity, but the first is regulated in a great degree by the necessity that exists under the climate of these provinces for preventing the growth of water weeds, and the second by the desire for maintaining the depths of water, corresponding as far as possible with the average depth of excavation; what is called technically in the department, "within soil."

The slopes of the bed therefore require to be dependent on the freedom of the water from vegetation, and at the same time the action of the current upon the soil. In the Ganges Canal works they have been limited to 2 feet per mile in the shingle tracts at the canal head, and to 1 foot per mile in the channel below them. From the Ranipoor super-passage, which lies at a distance of 6 miles from the head at Myapoor, the slope of the canal bed, in fact, varies from 1·25 to 1 foot per mile. These slopes are carried as uniformly as possible on long lines, and they are sustained at every bridge by the bay floorings, which act as retainers for restricting the effects of retrogression. For this purpose both the floorings and flanks of the bridges are well protected. It will be seen from what has gone before, that fall of country exceeding

the above slopes has been disposed of by abrupt masonry descents, over which the water passes; and that at the Solani Aqueduct and its neighbourhood, certain modifications of slope have been given, depending on the protective measures which have been thought necessary for that work.

The depth of the water, or that to which high-water mark is limited, was a point very prominently insisted on by the Medical Committee in the report to which I have drawn attention in an early part of this paper. It is one, moreover, of which I entirely approve, and to which, in fact, as much attention as possible was given in my original project. By restricting the high-water mark to a limit below the terreplein of the country, it is evident that all the dangers to which an embanked channel are open are avoided. This is a fact which directly attaches itself to the engineer not only in his estimate of cost, but of probabilities of accident. On the other hand, leakage and the proximity of hollows are the invariable attendants on raised embankments. The first, in very impervious soil, may be remedied, if not altogether prevented; but the latter is inherent in the design. Earth must be procured, either by superficial digging, *i.e.* by shaving from the surface a moderate quantity of earth, or by the excavation of tanks or reservoirs. In both cases rain water lodges, and during the rainy season forms jheels and sheets of standing water, leading to the richest vegetation, which is maintained even after the subsidence of the water by the moisture derived from the canal. To prevent the occurrence of embankments universally, is quite impracticable; but it may be reduced to the lowest possible limit, and the evil may be modified by a judicious application of drainage channels, or even by the maintenance of tanks, which might be kept supplied with water, and by constant care be prevented from becoming

receptacles for water plants. I have endeavoured to do this in the few cases where embankments have been indispensable; but I have no doubt that experience will show the value, if not the necessity, of relieving the outside of the embankments from local inundations by cuts made into the nearest line of natural drainage. On this point there is no necessity for entering further, as it has been repeatedly referred to in former chapters.

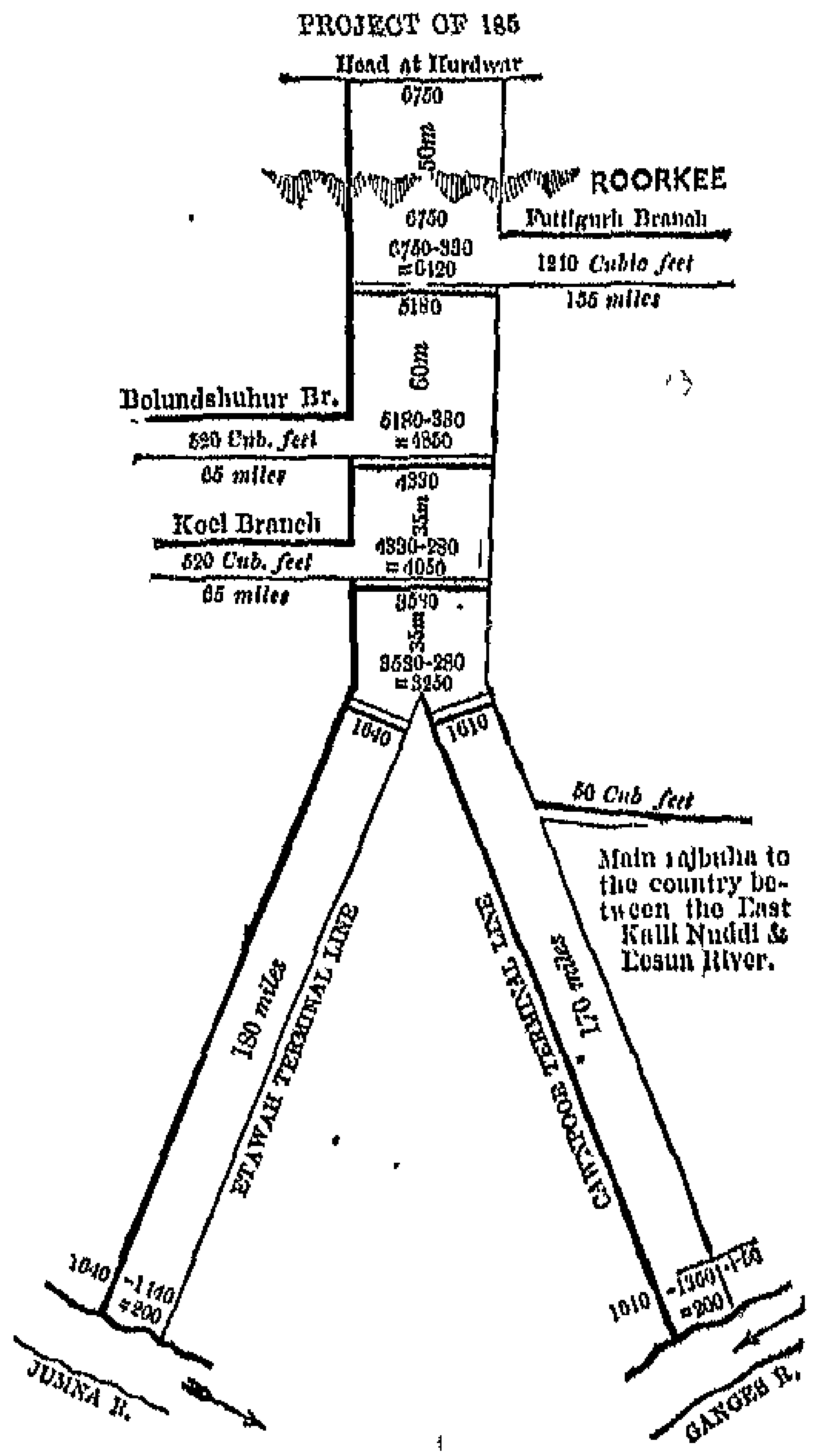
The amount of water which is to be admitted into the canal-head at Myapoor having been determined, and the detail of its distribution in the trunk and the different branches having been fixed, the plan that I followed in laying down the width of channel was to assume as fixed points certain leading features. For instance, it having been resolved that the discharge of water passing Roorkee should be 6,750 cubic feet per second, and that certain branches should be dependent on the main trunk for their supply, the axioms to which I have before referred gave me the exact amount of discharge required at—

The Futtigurh Branch Head.
Bolundshuhur Branch Head.
Koel Branch Head.
Nanoon Branch Head.
Escapes at the Heads of the Termini at the Ganges and Jumna.

The only modification required being that of adapting the main trunk *below* the branch heads and escapes to the additional volume that the stoppage to the branch-supply might occasionally furnish. On these considerations the skeleton, which I have shown in diagram 17, was designed, and it was upon this design that the canal channel has been excavated. To save back reference, the diagram above referred to is repeated, as it takes

its place very properly at the head of the following paragraphs.

Diagram 168.



The practical operations were conducted on two different plans, viz., one where the excavation was performed by contract, and in the other by labourers, either paid by the month or day, under the supervision of overseers. The first was the plan most generally adopted, although the latter has in many cases, especially in the work subordinate to the main canal, in the

Northern division, been very conveniently brought into requisition. The adoption of either, however, depended in some measure on the resources of the country in which the works were situated.

In the Punjaub, but more especially in those tracts of it lying on the frontiers of the North Western Provinces, between the Sutlej and Jumna Rivers, the excavation of tanks and water-courses has from time immemorial been a trade carried on by a class of people, nomad in habits, who attach themselves to any locality where work is plentiful, and where from the absence of restriction to grazing, their cattle can be allowed to wander about without interruption from enclosures. This class of people, who, under the name of "Oades," may, in their habits, be compared to the gipsy class in Europe, pitch their tents on the works, selecting spots free from cultivation, and in the neighbourhood of a well for drinking water. Their tents are in character like those of the gipsy. Pieces of canvas stretched on a pole, roofs of sirki, a species of matting made of grass, or rough covers of thatch composed of any sort of material that is at hand, constitute the residence of an "Oade." Here with his women, his cows, goats, and donkeys, the latter being the staple of his trade, he appears to live in as much happiness and comfort as the denizen of civilized abodes. He is quiet and tractable; and, excepting in occasional donkey raids on cultivated tracts, leads a life of repose, interfering with no one, and, in the absence of all wants beyond those of mere animal sustenance, is as free and independent as the gipsy.

In the very extensive excavations that have been made in the Northern tracts of the canal, people of this class have been collected in great numbers, and even in parts where the existence of cultivation has been greatly opposed to their natural habits. I have the authority from

Mr. Read, the executive officer, under whom they have been chiefly employed, that their conduct is exemplary. That the only cause of complaint, and that only in tracts where cultivation abounded, was in cattle trespassing. An evil which seldom or ever led to affrays, or was in itself carried to any serious extent. The people, in fact, appear to confine themselves to their own class, to be guided by certain municipal laws, and to be ruled by chiefs selected amongst themselves. Cases of misbehaviour are taken up by a punchayet or committee; the decision of which is accepted as law, and never appealed from to the district courts. A remarkable case of summary punishment inflicted on an interloper, who under the character of an "Oade," gained admission into a camp, and married one of the Oade women, may be introduced here in exemplification of simple and unsophisticated justice. It will illustrate the character of these tribes, and show the class of people with whom we were brought in connection. An athletic, fine-looking man, bearing in outward appearance the character of one who had been used to excavating, and in every way like one of this class of people, joined the works, and attached himself to an Oade encampment. A love affair, in which one of the Oade ladies was implicated, led to a marriage between the lady and the man who is the subject of the present story. The parties, after remaining some time in the encampment, absconded, the man in question having, by some act or other, shown that he was not an Oade. The discovery was not made for some days after the elopement, and the parties must have proceeded to a considerable distance before any steps were taken. No detective police in Europe could have acted with more judgment, secrecy, and quickness than did a chosen party of the tribe, who were immediately put upon the trail. Both man

and woman were brought back, tried with all due form, and judgment executed on the spot. The award was by no means a bad one, either for treacherous males, or for false females. Oade law painted both gentleman and lady in party colours of red, black, and white, seated them on two separate donkeys, with their faces turned towards the animals' tails, promenaded them through the different Oade encampments, and finally ejected them with ignominy from the precincts of the works. The whole of this proceeding was conducted with perfect gravity, and doubtless to the extreme satisfaction and approval of the collected tribes. This is one out of many instances of proof of an existing internal economy amongst this people, and their independence of action, even under the eye of the British police. The Oade is remarkable for the large size of the phaora (پھاوڑا mattock used in excavating) which he uses. It is frequently inlaid and ornamented, and is quite peculiar to this class of people. The use of the donkey for carrying earth is almost entirely confined to the Oade, who does not appear to employ either men, women, or children for this purpose. He is improvident, and appears to be satisfied with a mere subsistence. Time is to him a matter of indifference. With the nomad habits that he possesses, it is wonderful to see how he will procrastinate his departure from the ground of an encampment, if he sees the slightest probability of obtaining work, even at a distant period, in its vicinity. For months did Oade encampments hang about the neighbourhood of the Futtigurh Branch Head, under the hopes of the channel being commenced upon, and, I believe, that whatever difficulty there may be in collecting the parties on the commencement of a new work, there is an equal disinclination on the Oade's part to leaving when it is completed. This, however, is confined entirely to the northern tracts upon which the canals in these provinces

have been undertaken. In the Southern Divisions of the Ganges Canal works, the name of the tribe as contractors is unknown. The Oade loveth not the regions of towns and cities, or the proximity of agricultural industry. His fields are those where his goats and donkeys can feed unmolested, where he can enjoy fresh air and drink pure water. The tribes appear to depend in their accounts on a man selected from the "lalla," or bunnia class, who makes them small advances, and arranges the distribution on settling day. This appears to be universally the case when the Oades are working in large parties; but when detached, or carrying on works in small bodies, the cash settlements are made without the intervention of any middle man. The Oade contractor places implicit belief in the measurement made by the European officer, whose decision in all cases is looked upon as a point not to be disputed. With this simple class of people no written contract is entered into, and I am not aware of its ever having been abused. At least three-quarters of the Eastern Jumna Canal were excavated, under my own superintendence, by contractors of this class. By far the greater portion of the leading 110 miles of the Ganges Canal works was done by the same people, many of them children of those who had done so much work for me on the Eastern Jumna. I can speak freely of their habits as orderly and quiet to a degree that could hardly be understood by those who have resided in the neighbourhood of, or have in any way been connected with, European excavators.

Besides the Oades, there are numerous other classes of excavators, whose occupation, however, does not appear to be confined to digging. In such a large body of works each and all of these classes are represented, with more or less benefit to progress. Reference will be made to them in the detail of excavation.

Daily and monthly labourers have been chiefly confined to detached works in the Northern Division, to excavations for masonry works, and in the Cawnpoor District to parts of the canal channel. In making use of this species of labour, however, task work is demanded, that is to say, each man, or each party of men are bound to do a given quantity of work, a failure in which leads to a reduction of pay. An able-bodied man is supposed to execute 83·33 cubic feet per day. Cooli or carriage labour is dependent on the locality, and the distance to which the earth has to be removed. I shall enter on this subject more fully presently. As a rule, there can be no doubt that earthwork, especially that in embankments, is better done by daily labour than by contractors. The former is dearer in its original cost; but where embankments of made earth are concerned, it is, I believe, in the end cheaper.

With these prefatory remarks I shall enter upon a description of the canal excavation, separating it into sections or lengths, due to the quality of the soil with which we have had to contend. Under this consideration, the sections which I have enumerated elsewhere appear to be the natural divisions into which the description falls. Three great divisions, consisting of shingle to the north, sand in the centre, and clay in the lower regions, offer in abstract a statement of the nature of our excavations. These, with modifications due to local causes, give us the following:—

I. From the Head to Roorkee.

A. Supply Channel from the Ganges to Myapoor.
B. From Myapoor to the Puttri Super-passage.
C. From the Puttri Super-passage to the Rutmoo River.
D. From the Rutmoo River to the Assoffnuggur Falls.

A. *Supply Channel from the Ganges to Myapoor.*

This excavation consists of a channel excavated through the bed or branch of the Ganges, from a point above the town of Hurdwar to the dam and regulating bridge at Myapoor. It includes also very heavy excavation in the neighbourhood of the Myapoor works, the construction of bunds, and a quantity of shingle work subordinate to the purpose of taking the water from the main Ganges. This excavation is entirely in heavy shingle, or boulders, many of them of large size, and the whole very compactly embedded. The work is difficult and expensive, and very destructive to tools. The length of excavated channel, from the Ganges to the Myapoor Regulator, is 14,750 feet. Its width 300 feet, and its average depth 7½ feet. The slope of bed is equal to 8·59 feet per mile.

From the dam, on its down-stream side, a cut of similar proportions and slope of bed to that above described, also excavated in shingle, has been completed. This, and the extensive clearances in the neighbourhood of the works, including the excavations of the regulating bridge, were done partly by contractors and partly by daily people. The rates vary considerably, depending on the position and depth, but they average on the whole rs. 4-5-1 per 1,000 cubic feet. The maximum being rs. 6-6-1, and the minimum rs. 2-5-10, when daily labour was used. The rates to contractors per 1,000 cubic feet were rs. 6 and rs. 1-8-0 respectively. I may observe that, between the side of the high bank, on which the Gunes ghat was formerly situated, and the regulating bridge, the distance is 850 feet. The excavation on this line was through an upper soil of a very tenacious clay, with substrata of boulders; the total depth being 21 feet.

B. *From Myapoor to the Puttri Super-passage.*

The excavation on this line was the first that was undertaken on the Ganges Canal works; it was commenced on the 16th April, 1842, on which day the first ground was broken. The work was taken up by contractors of a variety of descriptions, the greater number of the class which I have above mentioned under the name of Oades. It was distributed in lengths of 25 feet, and the rates were fixed at

		RS.	A.	P.		
From surface to 5 feet in depth	. at	2	0	0	per 1,000	cubic feet.
„ 5 feet to bottom	. at	2	8	0	„	„
Boulder or gravel at any depth	. at	3	0	0	„	„

The excavation was commenced under my direct orders by Mr. Thomas Wright, an assistant executive officer, who died in 1846 after doing much good service. Captain Richard Strachey of the Engineers, however, who was afterwards appointed to the executive charge of the works in the Northern Division, has the merit of the organization of the establishments, and of placing the works on a proper footing; and I consider that much of the method and order which ultimately prevailed, is due to the indefatigable energy and well-known talent of that officer. With the exception of the tract immediately in connection with the Ranipoor torrent, which was sand, the line from the Myapoor Regulator consisted of a supersoil of a good firm clay, uninterruptedly to the neighbourhood of the Ranipoor torrent. From whence to the Puttri it became more mixed with sand, with occasional traces of shingle shown in detached pebbles. The substrata throughout were sandy, although for the two leading miles of its course, as far down as the site of the bridge at Kunkhul, the excavation on the lower 5 feet was through heavy shingle.

On this digging of which the sections were as follows:—

Diagram 164.

Fig. 1.—From Myapoor to the Ranipoor Torrent.

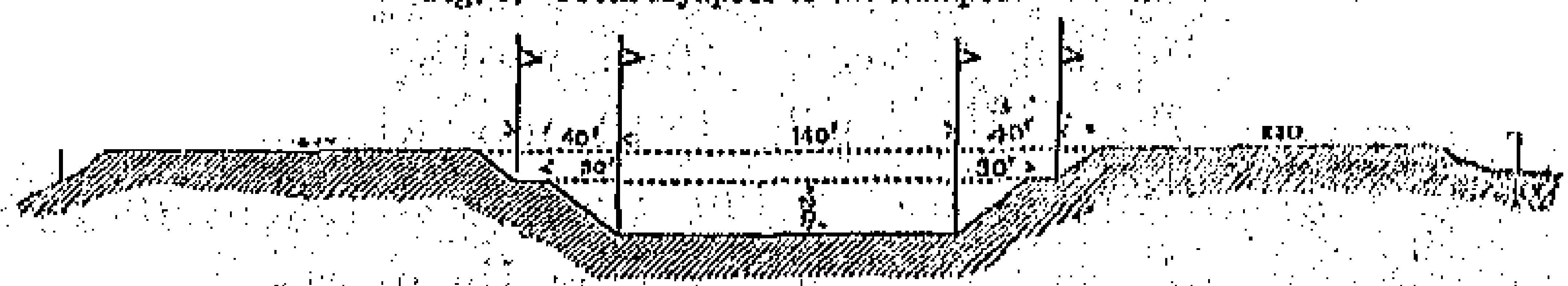
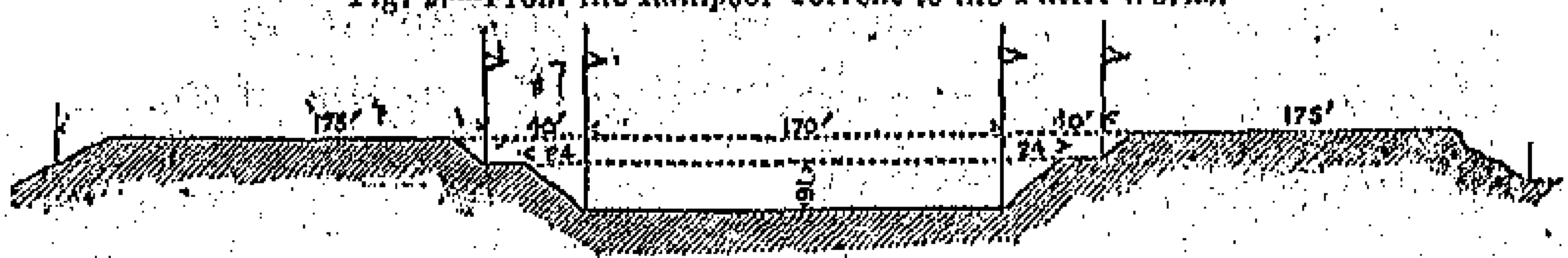


Fig. 2.—From the Ranipoor Torrent to the Puttri Works.



no spring-water was met with. The average depths on fig. 1 may be estimated at 18·6 feet,

And the maximum at 25·08 feet.
" minimum at 4·80 "

On fig. 2 the average depth was 16·5 feet;

Maximum 24·75 feet.
Minimum 10·73 "

The rates per 1,000 cubic feet will be understood from the following table:—

	RS.	A.	P.
From Myapoor to Ranipoor, per 1,000 cubic feet, average on whole	2	14	2
From Ranipoor to Puttri, per 1,000 cubic feet, average on whole	2	0	10

C. From the Puttri Super-passage to the Rutmoo River.

This is perhaps the most interesting line of work that has been excavated. It embraces the whole of the digging which, as I have explained in the early part of this paper, depended on the retroposition of the falls, so as to enable the Puttri torrent to be passed over instead of through the canal channel. The length is equal to 10,810 feet. On its course it passes through a ridge upon which the villages of Gurh and Saynibas are situated; and with the exception of the supersoil to a depth of from 7½ to 20 feet,

it is entirely excavated through earth impregnated with springs.

I have in the First Chapter, under the head of Super-passages, described the arrangements that were made at the Puttri super-passage for enabling the masons to work on the lower levels, lying 17 to 21 feet below the surface of the spring-water. The plan that was adopted there was pursued, on the line of excavation which I am now describing. The work was tedious and very expensive; it required, moreover, the constant vigilance of an active supervisor, to see that what was done in one day, was not by the action of the springs undone the next. The nature of the country through which this digging was executed was that of the Turai, before explained. The spring-water, which in the "Bhabur" belt is kept down by impervious superstrata, rises immediately it escapes from its bondage. At the Badshahpoor nulla, which is situated within 6,006 feet of the Rutmoo, and which is intersected by the canal, water runs in a perennial stream. The difficulties of excavating this portion of the canal, may be comprehended by referring to the stream in question, which naturally runs on a level of 8·18 feet above that of the canal bed. This nulla was merely an external exhibition of the spring level throughout the whole line of country to which I am now referring.

In the excavation for the Puttri super-passage works, it will be recollected that advantage was taken of the fall of country at right angles to the canal alignement, to carry a ditch from the canal in the direction of the slope, so as to give an escape to the water as it collected in the excavations. The effects of this escape were in the highest degree satisfactory. Under careless superintendence, it would have been useless. With the energetic supervision that it fortunately had, it was maintained in an open state throughout the progress of the work. It was this

persevering management, that enabled Mr. Login, the officer under whom the work was executed, to make any progress at all. The determined opposition of the springs acting in sand and mud, could only be overcome by the most minute vigilance, and by the constant application of remedies.

After removing the super-soil, or that unconnected with springs, an escape similar to that which was executed near the Puttri works, was made near the Badshahpoor nulla. The distance from the Puttri to this nulla is 10,804 feet, so that, in making use of the Badshahpoor escape for the relief of spring-water during the excavations, a considerable slope was available. The direction of the spring current was from north to south, or from the high to the low land. The canal channel intersected this at right angles. Mr. Login's plan of operations will be best understood by diagrams showing the line in plan and section.

Diagram 165.

Fig. 1.

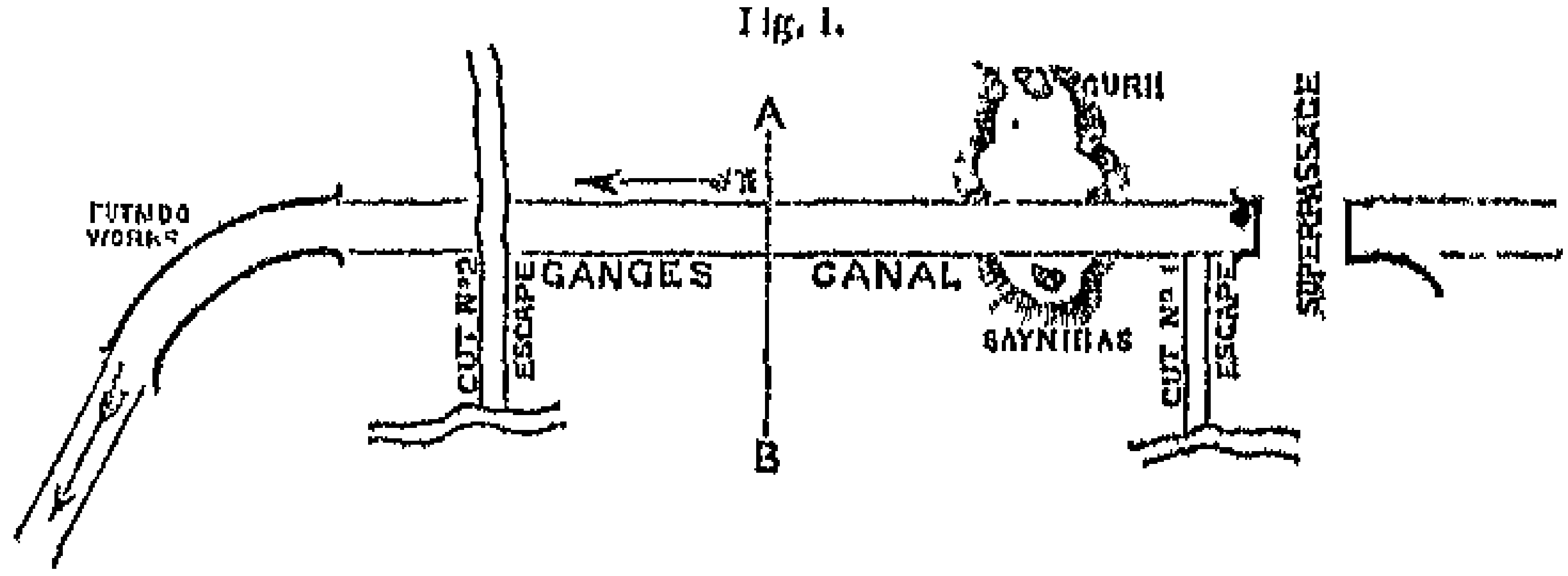
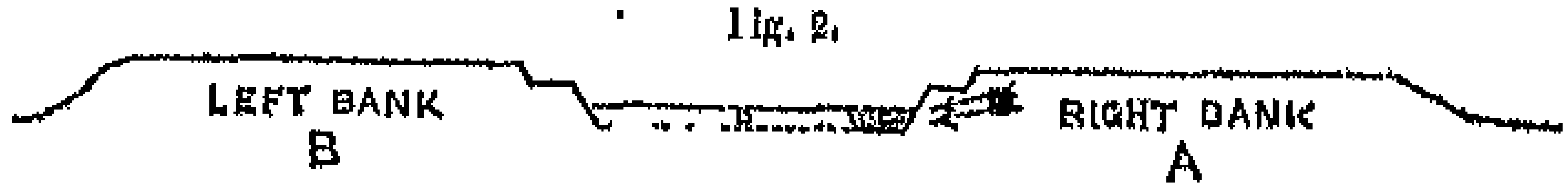


Fig. 2.



The true section of the canal in its full depth is represented by the dots. The way that this was reached will be understood by the shade C, fig. 2, which represents a ditch or cunette, in this case a catch-drain for the spring-water which flowed in the direction of the arrows. This cunette was carried along the whole line of excavation, and terminated in the escape No. 2. Both cunette

and escape were maintained in a constant state of efficiency as regards the free run of water. By the interposition of the cunette C, that portion of the canal channel at D, fig. 2, was excavated without trouble, as it was entirely cut off from its spring supply. The process was a very gradual one. As the depth of the cunette was increased, so did the portion D become relieved of its difficulties. It was an operation requiring especial care; and in a pecuniary point of view, the greatest attention to prevent the work of one day being obliterated by the action of springs during the night-time. The whole was completed, however; and I consider it to have been one of the most satisfactory works on the canal.

The section of the Northern Division figured on the opposite page shows the levels of the springs, on the whole line from Myapoor downwards. To this I would especially draw the reader's attention. I may observe, however, that between the Puttri and the Rutmoo, their maximum depth below the surface of the country was only 7¼ to 20 feet, whereas the depth of channel to be excavated was equal to 27 feet. The greatest depth of digging at the Gurh ridge was 42 feet; but this extended for a short distance only. The soil is more or less sandy, although mixed with clay, which, judging from the excavations and the block sinking at the Puttri works, lies in a narrow irregular stratum, without any continuity.

The work was done partly by monthly paid labourers, and partly by contractors, on rates as specified below:—

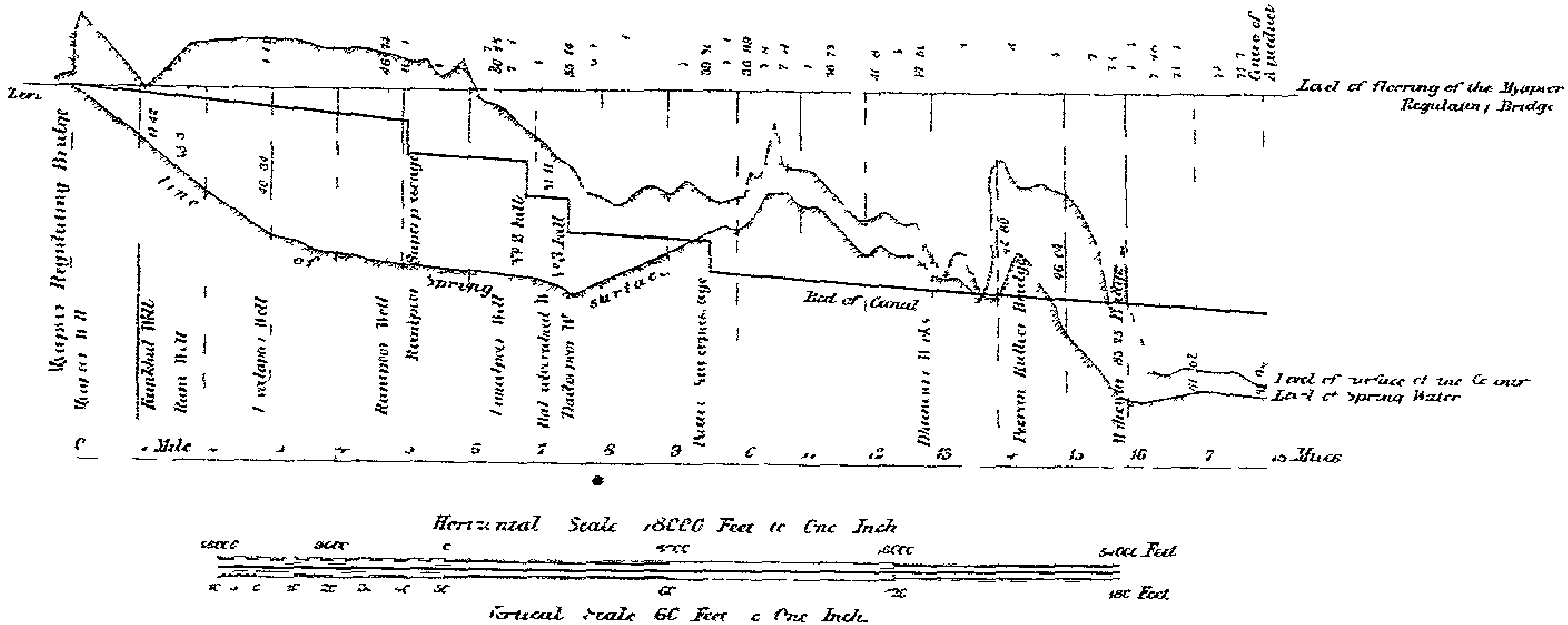
	RS.	A.	P.		
Average	2	14	0	per 1,000 cubic feet.	
Maximum . . .	4	2	0	"	"
Minimum	1	14	0	"	"

D. *From the Rutmoo River to Roorkee, or to the high land of the Doab.*

The valley of the Rutmoo, which is about one mile in

DIAGRAM CLXVI

SECTION OF NORTHERN DIVISION SHEWING DEPTH OF SPRING WATER.

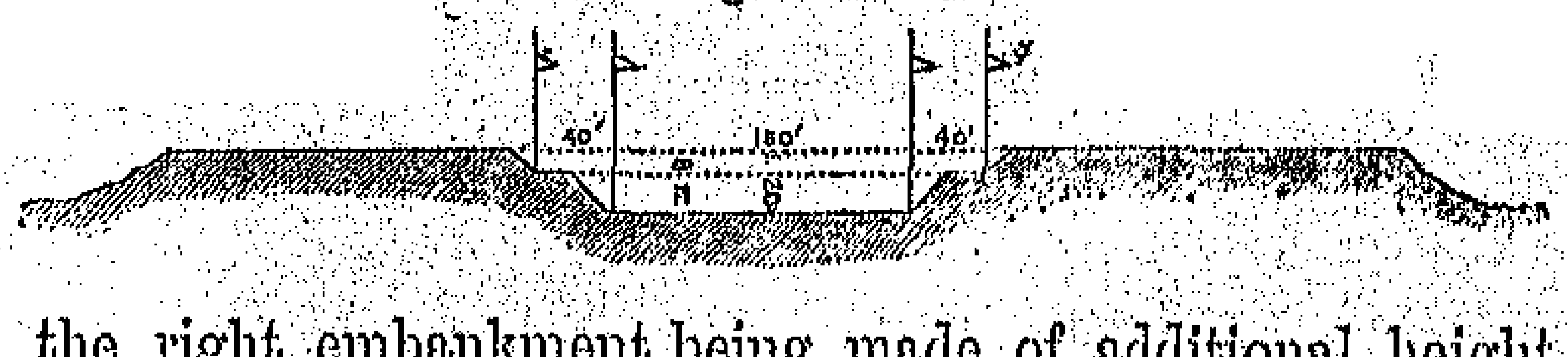


breadth, rests its right boundary on the Peeran Kulleeur ridge. This ridge, which is 2 miles in width, comes in contact on its southern boundary with the left of the Solani Valley, over which the great aqueduct is constructed. The aqueduct delivers the canal channel on Roorkee, at which point, having entered on the high land of the country, it may be considered to have passed its difficulties.

As the description of the whole of the Solani Aqueduct works, including the embankments, the earth for making which has been procured in a great measure from the Peeran Kulleeur ridge, is entered in a separate chapter; the subject of the present section relates merely to the embankments lying in the Rutmoo Valley between the Peeran Kulleeur ridge, and the right flank of the dam on that river, with general remarks on the ridge digging. The embankments here alluded to were partly made from earth, taken from the outside in trenches dug to a depth of 2 feet, and partly, although in a much greater degree, from the ridge. The former was done by contractors, and the latter by monthly paid labourers, who were employed on waggons running on tram-roads, or rails, in carrying the soil excavated from the high land to the lower levels on which the embankments were formed.

The section of the canal on these embankments is as follows:—

Diagram 167.



the right embankment being made of additional height and width, and both of them on their approach to the Peeran Kulleeur ridge having been laid out on extended dimensions.

The depths of channel digging, to gain the true canal levels, did not exceed 6 feet; the banks, therefore, have been a very important part of the undertaking; they have been well consolidated, however, and their proportions are on a large scale.

The average cost per 1,000 cubic feet was—

	RS.	A.	P.
Maximum	4	3	8
Minimum	1	10	6

Although the rates of excavation in the Peeran Kulleeur ridge are explained in detail when describing the aqueduct works, I may mention here that the depth of digging in its maximum dimensions was equal to 37 feet. The cutting, in fact, through this ridge, with the exception of a hollow near its southern limit, averaged in depth 31 feet. The soil consisted of parallel strata of sands and clays, perfectly horizontal, and corresponding with those on the Roorkee side of the Solani Valley. There were clear traces of a superficial deposit, probably of great antiquity, overlying an ancient surface, marked occasionally by depressions, in all probability those of drainage. This cutting was most remarkable from the presence of a stratum of blue clay 3 feet in thickness, like that which is commonly found in old tanks and reservoirs, connected with one of a reddish sand, replete with traces of carbonaceous matter, exhibiting themselves in form and appearance not unlike those connected with the lignite deposits so commonly found in the Sewaliks. Although a portion of the excavation, especially that near the village of Peeran Kulleeur, was done by excavators on contract, by far the greatest proportion of the earth was carried either to the Rutmoo or to the Solani embankments by railway. The cost per 1,000 cubic feet, in the first case, may be estimated at rs. 3-0-5. That on the railway work runs through variations depending entirely on the distance to

which the earth was carried, the average on a great number of rates, giving a cost of rs. 3-11-4 per 1,000 cubic feet of excavation.

II. From Roorkee to the Nanoon Regulators.

A. From the Aqueduct at Roorkee to the 110th mile.
B. From the 110th to the 180th mile.

A. This line of digging, passing through the Saharunpoor, Muzuffurnuggur, and Meerut districts, was commenced in 1842 simultaneously, or nearly so, with that in the Khadir. The works were organized under the management of Captain Turnbull, of the Engineers, and the canal channel was begun and completed almost entirely by the Oade class of excavators. In 1847, Captain Turnbull was relieved from his duties by Lieutenant Edward Fraser, of the Engineers, who resigned his charge to Mr. Frederick Read in the month of October, 1850.

The rate allowed to the contractors varied in the first instance from rs. 2 to 2½ per 1,000 cubic feet. This gradually settled down to a fixed standard, on which the work was carried to completion. Under this standard the rate allowed for a canal, the rectangular width of which was 180 feet, and depth 10 feet, with slopes 1½ to 1, was equal to rs. 1-14-0 per 1,000 cubic feet. To depths below 10 feet, the rates were fixed at rs. 2-6-0 per 1,000 cubic feet. The earth, in all cases, had to be carried on an average to a distance of 150 feet.

The system on which the contract work was performed, was simple. The contractors, (each of whom had a portion of from 50 to 100 feet in length of the channel allotted to him,) gave their work out to their

labourers or to sub-contractors at rs. 1-8-0 in the first case above mentioned; and at rs. 1-12-0, or rs. 2-0-0 per 1,000 cubic feet in the second. They (the contractors) finding the tools (phaoras and baskets) for the labourers.

Three able-bodied men will excavate and carry out 250 cubic feet per diem, and earn 6 annas, or 2 annas each, when the digging is not more than 10 feet in depth.

The actual rates at which this portion of the canal channel was excavated, were as follow:—

From the Roorkee Aqueduct to the 50th mile, the rectangular channel being 140 feet in width, the rates were rs. 2 per 1,000 cubic feet, to a depth of 10 feet from the surface, below which the rate was raised to rs. 2-8-0.

From the 50th to the 84th mile inclusive, the rectangular channel being 130 feet in width, the rates were rs. 1-14-0 and rs. 2-6-0, under the same restrictions with regard to depth.

From the 84th to the 105th mile inclusive, the rectangular channel being 120 feet in width, the rates were rs. 1-8-0 per 1,000 cubic feet.

From the 105th to the 110th mile inclusive, the rectangular channel being 110 feet in width, the rates were rs. 1-8-0 per 1,000 cubic feet.

The whole of the levelling and smoothing off of the embankments, together with the finishing of slopes, is included in the above-mentioned contract.

There are numerous curves on this line, the leading one of which commences at the down-stream terminus of the Solani Aqueduct. This curve is described on a radius of 6,617 feet. It is necessarily abrupt from the circumstance of the relative position of the aqueduct to the

direct line of excavated channel, to both of which it forms tangents. Its concave or right side has been protected by a masonry revetment. The Liburheri curve is a gradual one, on a radius of 57,456 feet. Those from Bailra to Jaoli are on radii of 44,480 feet. That at Sulawur, 4 miles; and the great curve to the south, which brings the canal to bear upon the country lying between the Kuroon and the East Kalli Nuddi rivers, may be described as a polygon with the corners cut off by curves on radii of from 8 to 5 miles in length.

The supersoil throughout the whole of the country from Roorkee to the 110th mile consists of clay overlying sand. The depth of this superstratum of clay varies from 10 to 4 feet. On the whole tract, the surface of the country is marked by sand ridges, which appear most prominently between Roorkee and Muzuffurnuggur, as well as on the line from Bailra to Khutowli. These sand ridges appear again in great force in the neighbourhood of Sirdhunna. No spring-water was met with in excavating the canal channel, although the foundations of masonry works came in contact with it at all the works from Sulawur, downwards. As a characteristic feature, the whole of this line through which excavation was carried, may be considered as sandy. A great portion of it was land used either for khurreef or rain-crops only, or for cold weather crops sown in dependence on the rain that falls during the months of November, December, and January. It is remarkable for its dryness, spring-water being found at great depths. The excavation on the whole line may be considered easy, and progress was carried on without any interruption.

There are two points on this line where the levels of the canal bed were so little depressed below the surface of the country, that it has been necessary to raise embankments to complete the canal channel. The

value of the works at these points may be estimated by the following diagrams:—

Diagram 168.

Section of Canal at Toghulpoor.

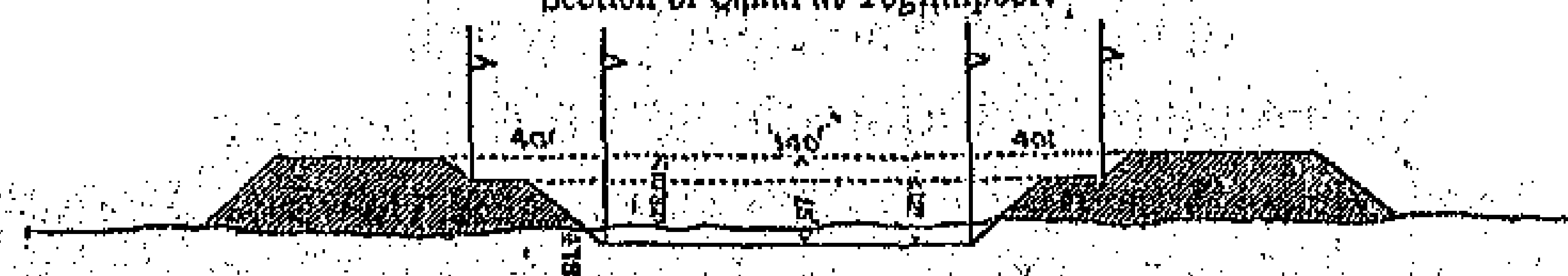
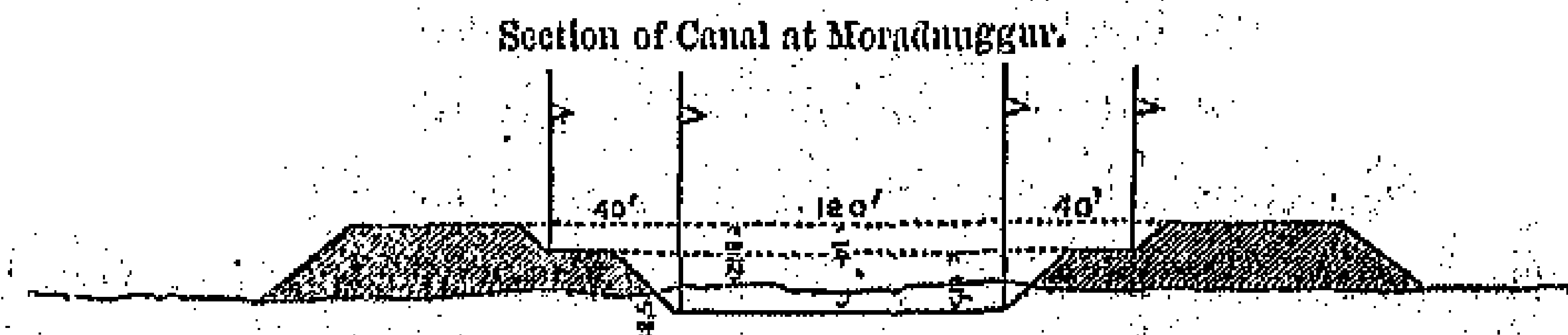


Diagram 169.

Section of Canal at Moradnuggur.



The shaded portion represents the artificial work, which is made of earth, well rammed and watered, built in layers of 2 feet in thickness. These embankments are situated at Toghulpoor, and at Moradnuggur. In the former case, the length is equal to 4,900 feet; in the latter to 7,100 feet. The earth required has been collected from superficial excavations in the neighbourhood, excepting in extraordinary cases, where, as at the Toghulpoor and Moradnuggur bridges, a deficit in material has been made up by digging circular tanks, centrically situated on the right angles formed by the bridge ramps and the canal embankments. As the greatest care has been given in the construction of these works, I do not consider that they will lead to disappointment. I am not quite satisfied with the outside hollows from which the earth has been taken. They have now, however, existed for some years without giving annoyance, and it is, therefore, possible that from the absorbent nature of the soil, the water that would otherwise collect is rapidly absorbed. I have in no case allowed inlet to be carried into the canal channel for reasons which have been fully explained

before. Should difficulties, therefore, exist hereafter, drainage cuts, in the way which has been laid down for guidance, must be excavated, so as to connect these hollows with the low land lying near the beds of the rivers on the right and left. The rajbuha system which entails such a reticulation of watercourses over the surface of the country, will so completely change and modify the natural water-shed, that until its effects are shown, it appears to me to be unwise to lay out drainage cuts, excepting such as are indispensably necessary for present purposes.

The excavation of the three escape channels at Khutowli, Muhummud Aboo's Nulla, and Janni Khoord, was carried out in the same way as that of the main trunk. From its reduced size the rates were reduced to rs. 1-8-0 per 1,000 cubic feet.

The rates of digging, including contingencies of sorts, may be understood from the following table taken from the bills submitted by the different executive officers who have held charge of these works.

By whom executed.	In what Locality.	Rate per 1,000 cubic feet.
		RS. A. P.
Lieut. A. D. Turnbull	From 24th to 50th mile	2 4 8
Lieut. E. Fraser . .	" "	2 0 11·9
" . . .	" "	2 1 2·5
" . . .	" 50th to 110th mile	1 15 10·1
Mr. F. Read . . .	" "	1 15 0·6
"	" "	1 15 0
"	" 24th to 50th mile	2 0 11
"	" 50th to 110th mile	2 0 4·2

B. *From the* 110*th to the* 180*th mile; or to the Nanoon Regulators.*

The excavation here was done under the management of Mr. Philip Volk. The dimensions of the canal

in their extremes are shown in the following diagrams.

Diagram 170.

Section at the 110th mile.

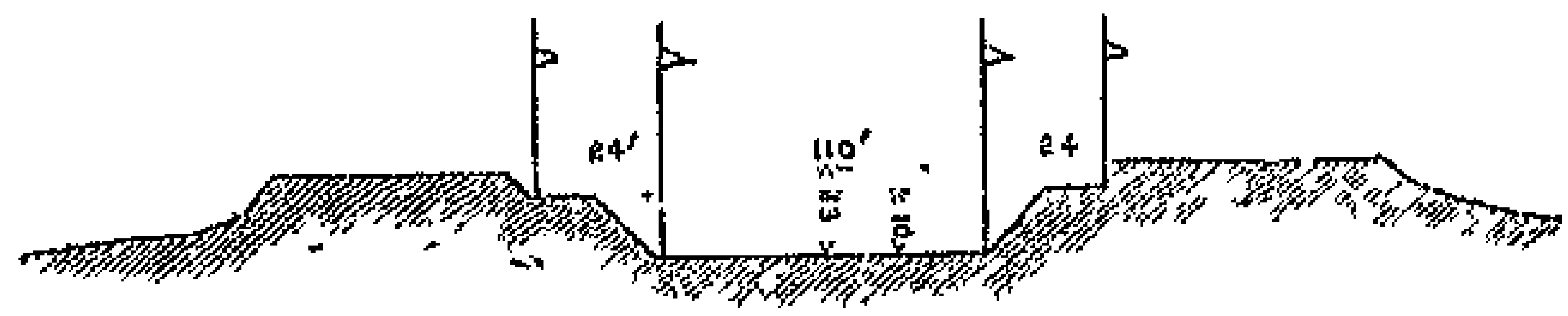
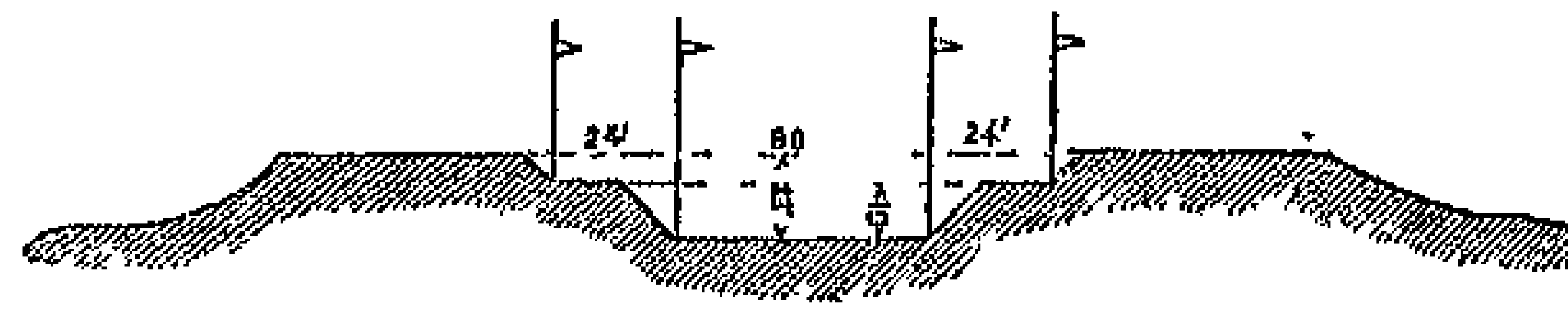


Diagram 171.

Section at the 180th mile.



The work is carried through the Meerut, Bolundshuhur, and Alligurh districts. The soil is of a better description than that of the Saharunpoor and Muzuffurnuggur districts above described. It consists of a good earth, although sand shows itself, more or less, at depths even with the canal bed. The country is, generally speaking, highly cultivated, although, in the neighbourhood of Khoorja, where we again come in contact with sand ridges, and in comparatively low ground in portions of the Alligurh district, cultivation is less abundant. Springs were not met with in the excavation of the canal channel, although, in the block foundations at the Simra Falls, we come in contact with them at a depth of 9½ feet below the level of the canal bed. As a general rule, the soil is better here than it was in the line from Roorkee to the 110th mile.

The highly-cultivated state of the country acted as a bar to the Oade contractors taking up work under Mr. Volk. They carried on progress up to the head of his division in prosecution of the work which they had begun under Mr. Read, but they refused to commence a new

series under the difficulties offered by cultivation to the maintenance of their cattle. The early part of Mr. Volk's operations, therefore, were prosecuted under many interruptions, but of a nature so similar to those that I met with in establishing the works in 1842 at Kunkhul, that I cannot do better than describe them in Mr. Volk's own words :—

"At the beginning of the excavation of the Third Division (that is, that of which I am now writing), considerable difficulties were experienced in procuring contractors and labourers, although, previous to the commencement of the works, many parties had forwarded applications for contracts. The cause of this keeping back was said to be dissatisfaction with the rates, and the hope that by delaying, more favourable terms would be offered. Several parties that had already commenced work left the canal, declaring that they could not continue to work at a loss.

"Several months passed away, during which time I commenced working with small parties of daily labourers, which measure had the beneficial effect of convincing the contractors that their intriguing would not prevail on me to raise the rates. Finally, work commenced under contractors.

"The rates for excavating 1,000 cubic feet vary from rs. 1-8-0 to rs. 2, according to the nature of the soil, the depth of canal, and the distance to which the earth is to be carried. For this sum, the contractor engages to dress the slopes, towing-path, and banks, to make all the required daghbels (linings-out), to excavate the boundary ditch, to make a road along the canal as far as his contract extends, and to keep the same in repair until his accounts are closed and settled.

"No advances of money were given. Monthly, once or twice, payments were made for the work executed,

keeping one-fifth to one-eighth in arrears, as a security for the faithful execution of the agreement on the part of the contractor.

"The contractor had to furnish his own tools, keeping them in repair at his own expense."

The men who were thus employed on contract work were of all denominations, many of them taking up long lines. The maximum extent of any single contract was equal to 3 miles, the minimum to 100 feet. The work has been very neatly executed, although there appears to have been more trouble with contractors of the sort engaged on this line, than there was with the Oade excavators. In all cases of contract, moreover, written papers were signed and sealed before the work was begun, and upon the letter of these agreements the work was executed.

Throughout this line, the berm, or towing-path, has been formed on one level with reference to the canal bed. Where the natural surface was too high, the superfluous soil was removed; where too low, soil was added to it. The whole section is on one uniform design, without the irregularities that have been described as existing in the tracts below Roorkee, and as far as the 110th mile; where the nature of the soil, and the extreme depths to which the excavations were necessarily carried, were opposed to a perfect uniformity of berm levels.

From the 176th to the 179th mile, a good deal of embanking has taken place, the necessity of which will be understood by a reference to the longitudinal section of the channel. The earth required for these embankments has been procured by excavating tanks or reservoirs on the outside of the canal boundaries, to an extent equal to the cubic content of material required; the depth of each tank being limited to the rates of superficial digging. It has been an object here to make these tanks

as deep as possible, without proceeding beyond that due to the above rate. The depths, therefore, do not exceed 10 feet, which it is supposed will be sufficient (if the tanks are kept filled) to prevent the growth of water-plants. It is proposed, also, that their preservation free from reeds and vegetation, should be considered a part of the conservative duties of the division; that means shall be taken for keeping them filled with water from the rajbuha heads; and that they shall act as supplies for machinery irrigation to the lands lying on their borders. There was a choice between two evils. Either by taking a superficial foot from the country, by which the carriage of material to the banks would have been enormously expensive, and a very extensive depression of surface would have been carried over large areas, leading to probable inundation during the rainy months. Or, by excavating deep reservoirs, which, whilst they afforded material for the required purposes of embankments, acted as recipients for the rain-water, which in the former case would have been scattered over the surface in the form of inundation. The position of the canal with reference to the beds of its boundary rivers, is such that there can be no difficulty in getting rid of inundation.

The rates per 1,000 cubic feet for excavation, including contingencies, are shown in the following table:—

	RS.	A.	P.	
Main canal	1	12	8	per 1,000 cubic feet.
Escape channels . .	1	5	0	" "

III. CAWNPOOR TERMINAL LINE.

The excavation of this canal was commenced in the cold weather of 1849–50; the leading 100 miles under the management of Lieutenant Hodgson, and the last 65 under that of Lieutenant C. W. Hutchinson, of the Engineers. The work was completed by the former officer. The

dimensions of the channels on its extremes, are shown in the following diagrams:—

Diagram 172.

Section at the head, or 1st mile.

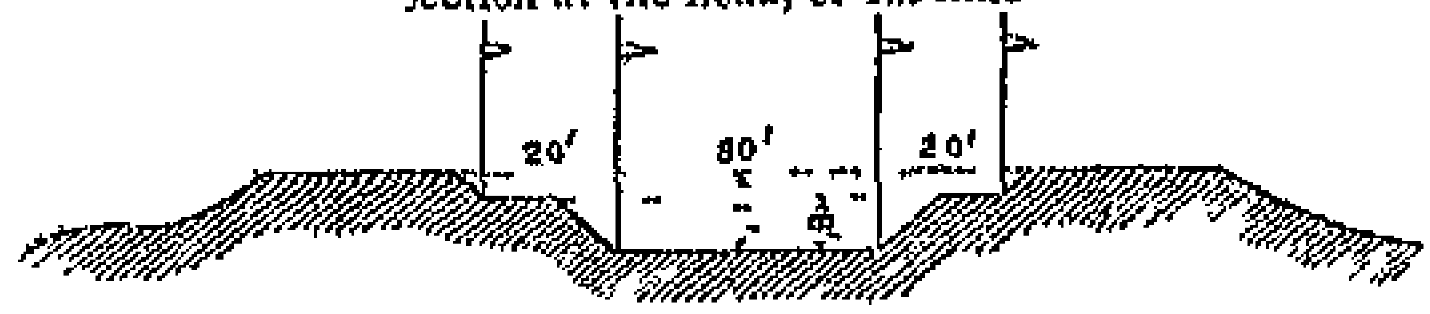
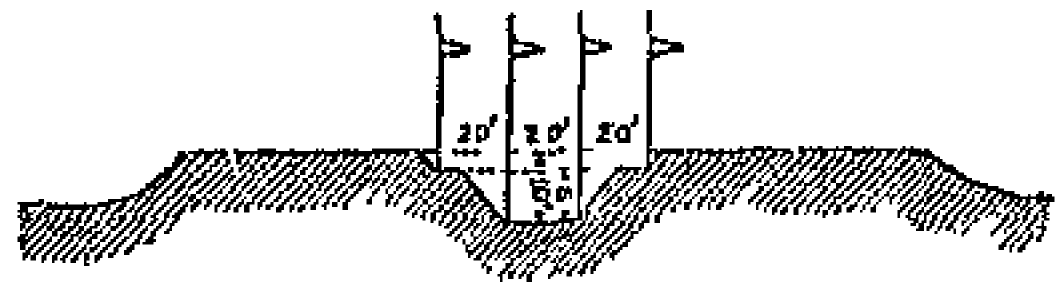


Diagram 173.

Section at the Duknapoor Bridge



The state of the country through which this line is carried is, generally speaking, well cultivated. It is richly so at many parts, especially in the Cawnpoor district. Elsewhere it is traversed by extensive plains, but where these are absent the cultivation is of a high order. The existence of these open plains is dependent, in a great measure, on the presence of reh, or soda, with which the soil is impregnated. The surface is hard and intractable at these points, although the subsoil is worked without much difficulty. Kunkur presents itself in great quantities throughout the whole of this region. It appears to me to be almost universal. Where it is not found in block, it is found in gravel; and as the whole of it is highly calcareous, its presence is a great resource in masonry building. The presence of reh is very detrimental to earth required for brick-making, although, in other respects, time only can show in how far it will affect the value of the canal as a channel for distributing water to the irrigators. From the observations of the few years that have elapsed since the excavation was begun, I should conclude that the soil throughout is of a very retentive nature, and that in this respect it will be favourable to economizing the supply.

There appears to have been greater difficulties here even than in the Bolundshuhur district in getting contractors, and, *in many cases, in collecting* workpeople at all. This arose, undoubtedly, from our having arrived at a still greater distance from the tracts frequented by these people, and in all probability from a desire on their part to force us into an increase of rates. Lieutenant Hodgson, who had the control of that portion of the line passing through the Alligurh and Mynpoori districts, commenced operations by establishing two classes of excavation, viz., one confined to that of the rectangular section, and the other for removal of the slopes. For this, he determined averages of rs. 1-14-0 and rs. 1-10-0 per 1,000 cubic feet: the first, on the early part of the line, where the width of the rectangular section varied from 80 to 64½ feet in width; the latter, on its decrease to a width of 40 feet. It was upon these rates that my estimate of 1850 was framed. Circumstances, however, which can be best explained in the words of Lieutenant Hodgson's own report, necessitated an increase, and there can be no doubt that such was justifiable. Lieutenant Hodgson observed:—"The rate of rs. 1-10-0 per 1,000 cubic feet of excavation was fixed by me, under the belief that contractors to whom I had given out work were carrying it on without difficulty at the rates of rs. 1-3-0 to rs. 1-4-0 per 1,000 cubic feet, for the mere excavation of the rectangular section of the channel, exclusive of slopes, and the final formation of banks, for which I calculated that only a small addition to the rate would suffice. I have, however, since then found out that for a distance of 12 miles, throughout which I had broken ground, the contractors have *been paying their labourers at the rate of rs. 1-8-0*, and rs. 1-9-0, for the mere excavation of the centrical part of the section, and throwing the earth into irregular banks.

"The work being only carried on by means of advances to the contractors (on which plan alone did I find it possible to obtain them), it was not for some time that I discovered that this had been the case; nor, indeed, until very lately, did I make myself certain of the extent to which it had been carried; and since the discovery, I regret to say that work has almost stopped, owing to the labourers refusing to work at rates very materially lower. Indeed, whilst working at the high rates I have mentioned, I was continually met by complaints from them of the small remuneration their labour obtained. However, that a rate lower than those will be accepted by them, after the lapse of a little time, I have no doubt, from the experience in the other parts of the workings; yet it is perfectly clear that a higher rate must be allowed than I formerly supposed, and this more especially in all the shallow diggings and oosur (reh, or soda) soil, which, in the advanced part of the line not yet opened upon, prevail to a very great extent.

"That in some parts of the last 80 miles of the digging, the rate of the finished work will not exceed rs. 1-10-0 per 1,000 cubic feet, I hope; but that that will be the lowest seems clear, for I am now in several places completing portions, including the formation of banks; and the extra payments for the latter work, and also for cutting the slopes and making the boundary ditches, have brought the cost up to rs. 1-8-0 per 1,000 cubic feet. To this will have to be added a small amount for planting grass on the slopes and also a per-centage for expense of establishment, which will leave almost nothing to provide for keeping in good order the slopes and banks previous to the completion of the several miles or portions for which bills will be submitted. I must also add, that on no part of the works are either the contractors or labourers satisfied; of the former, I am per-

fectly aware that the profits have been nothing scarcely, and the latter do not on an average make anything approaching to the usual daily payment of six pice that prevails in the department of public works. My experience from actual excavation of the work as yet extends as far as the 56th mile to a width at bottom of 57 feet, so that I can only judge of the probable cost of the lower part of the division very imperfectly; but it is clear that, as far as we have yet gone, the rate per 1,000 cubic feet has not decreased, but, on the contrary, increased with the smaller dimension of channel. This can only be accounted for on the supposition that the class of labourers required are more abundant at the head of the division than in the lower parts. At the same time, I find that the proportion of carriers to diggers amongst the squads of workmen does not differ in parts 80 feet and 60 feet wide; and it is clear that a very trifling, if any decrease in the rate can be made for decrease of width of channel; whilst the cutting away of slopes, the formation of banks, and the contingent expenses, remain the same for both sections, and consequently bear a much greater proportion to the plain digging in the narrow than in the wide section, thereby causing rather an increase than a decrease to the rate as the canal narrows.

"The cheapest parts of the digging are the deepest, and such are the parts in which I have stated that I am completing work for rs. 1-8-0 per 1,000 cubic feet. The reasons of the lower cost in such parts are obvious, they being always in cultivated lands, and the harder surface soil and the stratum of kunkur (invariably to be cut through) bearing a much smaller proportion to the softer under soil (generally in such situations partly sand) than in shallower places.

"The 12 miles I have before alluded to, are from the

46th to the 58th, throughout either not exceeding 5 feet in depth, consisting of oosur soil, mixed intimately with small kunkur and bujri, all unfit for use from its impregnation with soda. There are also parts where the kunkur formation is partially consolidated, which is very hard to dig through. The latter parts are of course exceptional cases, and the high rates there will admit of explanation. At present no one will dig in them.

"To state, then, the rates which appear to me now likely to cover the expenditure:—

"From the head of the division to the 60th mile, on the whole number of miles, and exclusive of the embankments in the 20th and 27th miles, rs. 1-14-0 per 1,000 cubic feet; but that in some miles this rate will be exceeded, and especially in such parts as present partially formed kunkur.

"Then, from the 60th to the (end of the division) 100th mile, considering the great prevalence of the oosur soil; the greatly increased rates of contingent expenses to the absolute outlay on the labour of excavation; and also to the difficulty experienced in either obtaining contractors or labourers by Lieutenant Hutchinson in that part of the canal lying below my division, I cannot but anticipate a rate somewhat higher than the above, and therefore beg to put it at two rupees per 1,000 cubic feet.

"In the above calculations I have taken into consideration the positive value of kunkur if separated from the earth, for which I pay extra for obtaining it so separated, crediting the excavation with the value of it.

"I must further add, that the contractors who have made payment to the labourers in excess of the sums stipulated for in their agreement papers, are in no case scarcely able to make such sums good, and that, therefore, there will be a loss in this part of the works which will, I fear, amount to from 700 to 800 rupees."

The above gives a fair account of the difficulties which occurred in the early part of progress on this line of the excavation. Lieutenant Hodgson's intentions in fixing low rates were deserving of all commendation; and although he failed in so far that an increase was inevitable, the effects arising from the inquiries that this lowness of rate led to, were undoubtedly favourable to his ultimate progress. After all, the rates which were determined after so much inquiry and experiment, were merely those of my original estimates, which amounted to two rupees per 1,000 cubic feet.

The *remarkable fact in this division was that contracts* were taken by men who apparently had never undertaken work of the sort in their lives, who were perfectly ignorant of the cost of excavation, and who trusted entirely to their tukdeer (destiny) for fortunate results. The *failure above described by Lieutenant Hodgson is a* remarkable example of this infatuation. The conduct of these people would, in England, have been called knavery, and the supervisor who did not take advantage of it would in all probability have been found fault with. Lieutenant Hodgson might certainly have left these contractors with their written agreements to suffer the loss themselves, but he acted judiciously in not doing so, and his proceedings in this case did, in all probability, do more towards rendering his board of works acceptable to people who were by no means ready to join them, than anything else that he could have done. The men, in fact, who failed on this occasion, succeeded afterwards; and Lieutenant Hodgson had nothing to regret in leaning to the favourable side of the question in these early failures.

The rates at which work has been executed under *Lieutenant Hodgson in the first hundred miles of the* Cawnpoor Terminal, will be seen by the following table;

and considering the difficulties to which I have drawn attention, they are very fair and reasonable:—

Locality.	Rate per 1,000 cubic feet. RS.	A.	P.
From 1st to 20th mile	1	11	8
„ 21st to 36th „	1	10	11
„ 36th to 50th „	1	9	10½
„ 50th to 75th „	1	12	9

As a general rule, the berms or towing paths have been maintained on a level parallel with that of the canal bed. Deviations from this rule have only been allowed in extraordinary cases, where a great saving of expenditure would be ensured. In such cases the higher levels were gained by very long slopes, the rise and fall of which are almost imperceptible.

From the 100th mile to the terminus at Cawnpoor, the excavation was commenced in the cold weather of 1849 by Lieutenant C. W. Hutchinson of the Engineers, who, on his departure on medical certificate in September, 1852, made over the works to Lieutenant Hodgson.

Lieutenant Hutchinson's interruptions were a repetition of those which have been before described, with perhaps additional difficulties in procuring labourers. The tract of country over which his line of works was carried extended through the Futtigurh and Cawnpoor districts,—26 miles of the former and 44 of the latter. The Futtigurh district was very similar to that described as existing in the first 100 miles of the course of this terminal line, intersected by a good deal of oosur and waste land, but richly cultivated elsewhere. Waste land was not so prevalent in the Cawnpoor district, the greater portion of the channel passing over country cultivated in a very high degree. Lieutenant Hutchinson shall describe his own impressions on the interruptions which he met with, as stated officially to me in a letter dated 1st February, 1851:—

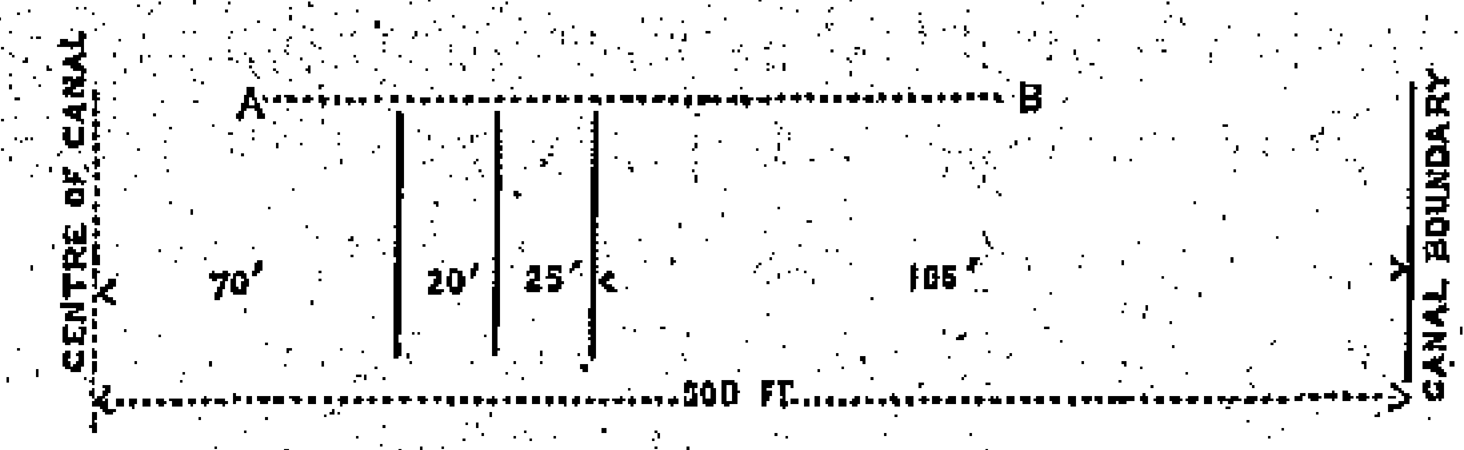
"As regards excavation of the canal, you observe 'that this is a thickly populated district, and that therefore we should experience no difficulty in procuring men.' The Cawnpoor district *is* a thickly populated one, and it is also most prosperous and fertile; the labourers for the most part are well off, and will not leave their fields to work on the canal. Very many have left the district and gone to the divisions of the canal farther west, as the impression appeared strong amongst them, that the rates there gave greater chance of profit. When we first commenced excavation, the rates we held out, rs. 1-2-0 per 1,000 cubic feet, were undoubtedly too low, and the report spread that here there was no profit to be made. This completely stopped our works for a time, and it was not till August, 1850, that we may be said to have got over this impression, and commenced work, giving higher rates. Since then the work has been progressing and improving rapidly, with the exception of about six weeks, when our works were nearly deserted by the labourers going to cut the khureef crops. Even now, however, squads of labourers frequently leave their work to go for a few days to any fair or wedding, and then come back again. If a day's rain falls, the works are deserted, and it takes a few days to collect them all again. I would beg also to draw attention to the Military Board's circular, No. 422, dated 1st October, 1850, in which the officer of the Grand Trunk Road in this district has shown that he finds his earthwork costs him, including dressing, &c., rs. 1-8-2 per 1,000 cubic feet. At this rate I could push on work much more rapidly; but I have been endeavouring as much as possible to keep the rates of my work within my estimate of rs. 1-6-0.

"I also beg to point out, with reference to my rates as compared with the Second Division, that when the section becomes so narrow as it does down here, the

quantity of dressing and sloping remains the same, whilst the proportion of the mass dug in the rectangle is much increased.

"For example, if the rectangular section be 140 feet broad by 9 feet deep, and width between the canal boundaries 600 feet,—

Diagram 173.*



the mean distance earth is carried is $AB = 172\frac{1}{2}$ feet.

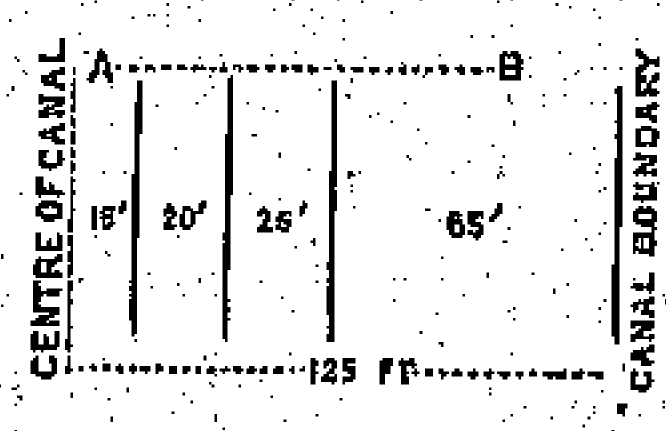
In a mile of rectangular channel the cubic content is	$140 \times 9 \times 5{,}280 = 6{,}652{,}800$
In a mile of slopes	$9 \times 9 \times 5{,}280 = 427{,}680$

the proportion of slopes to rectangle being 1 to 15·5

"If rs. 1-14-0 be the rate fixed for the whole work, then 7,080,480 = Co.'s rs. 13,275-14-0; and if we suppose the slopes to cost the contractor 6 annas per 1,000 cubic feet more, then 427,680 cubic feet at 6 annas per 1,000 = rs. 160-5-0.

"When the average section is, as here, $30' \times 9$, and width of canal land 250 feet,—

Diagram 173.**



the mean distance earth is carried is $AB = 85$ feet.

In a mile of rectangular channel the cubic content is	$30 \times 9 \times 5{,}280 = 1{,}425{,}600$
In a mile of slopes	$9 \times 9 \times 5{,}280 = 427{,}680.$

(the same in both cases), the proportion of slopes to rectangle being 1 to 3·3. If rs. 1-6-0 be the rate fixed for

the whole, then 1,853,280 cubic feet = rs. 2,548-4-0; and supposing the slopes to cost as much more in this case as in the other, viz., 6 annas per 1,000 cubic feet, then 427,680 cubic feet at 6 annas per 1,000 = rs. 160-5-0.

"In the one case the contractor deducts from his profits rs. 160-5-0 from rs. 13,275-14-0; and in the other rs. 160-5-0 from rs. 2,548-4-0.

"There is no doubt that the sloping and dressing is the most expensive part of the work, and my object in making the above rough calculation (which is, of course, not actually correct, as I do not know the rates or section of the second division), is merely to show that the quantity of sloping and dressing is the same everywhere, and how small in proportion it bears in a wide section to the mass of digging in which profit is made, as compared with the proportion in a narrow section. The distance of earth thrown in the first case is double that in the second; *but if the rates are as I have calculated them* (rs. 1-14-0 there, and rs. 1-6-0 here), I consider that 8 annas per 1,000 cubic feet is too large a difference for the mere carriage of earth 85 feet. On this point, however, I am not certain; if this is, as I suppose, too large a difference, it follows that the rates there are more remunerative than they are here, and consequently the greater difficulty of procuring men and contractors that exists here. As I before stated, however, I think that my difficulties as regards excavation are in a great measure overcome, and I trust that this work will now progress rapidly."

With the exception of the depths of digging in the second division, which were, generally speaking, much in excess to that noted by Lieutenant Hutchinson, his comparison is a true one. There is no doubt whatever that the proportion that the expensive work in slopes and dressing bears to the cheap, or rectangular excavation, is a matter of great consideration *to a contractor, and that*

he prefers wide channels to narrow ones on this account; but where great depths, entailing the carriage of earth up steep ascents, and upon long distances, as was the case in the second division, were the principal sources of expense and difficulty, there can be no doubt that the cost was comparatively cheaper. This, however, arose from the presence of the professional earth contractors, who took to the excavation with a perfect understanding of what they had to do. In the districts below Alligurh the people who undertook work appeared to be in most cases men who had not been previously engaged in excavation, and were actually ignorant of many of the simplest parts of the profession. This led to the necessity of a supervision and watching, for which with the regular earth contractor there was no need; contingent expenses unknown in the second division were, therefore, heaped upon the original contract rates. In the upper parts of the canal, in fact, we worked with professedly educated people. In the lower we had to educate them ourselves, and to submit to all the disappointments and expenses attendant thereon.

Before Lieutenant Hutchinson left his work in 1852, the greater proportion of the channel had been excavated. By separating the contracts for slopes from those of rectangular digging, however, he left to his successor a legacy which, in effect, was like that which he refers to in his comparison of rates. He had completed the greater proportion of the cheap digging, or rectangular section, whilst he left to his successor the completion of the slopes, or that portion of the work upon which he, in his comparison above given, places 6 annas in addition to his estimated rate for excavation. Although, therefore, Lieutenant Hutchinson's bills, as submitted, showed that he had done work at rs. 1-7-2·7 per 1,000 cubic feet, and, therefore, had worked very

closely with his estimate; he left to his successor the onus of doing the more expensive portions, unaided by the relief which a fair proportion of rectangular digging would have given to him. Lieutenant Hodgson had, in fact, to complete a great detail of finishing off of berms and banks, as well as slopes, the whole of which had been left incomplete.

The berms, or towing-paths, are constructed on the same plan as was adopted in the upper part of the Cawnpoor terminal. As a rule they were made parallel to the canal bed. Where this was not the case, the rise and fall were made as gradual as possible.

The rates of excavation as submitted by Lieutenant Hutchinson were as follow:—

	R.	A.	P.	
Average rate all over Lieutenant Hutchinson's work . . .	1	7	2·7	per 1,000 cubic feet.

Since August, 1852, as I have before noted, the whole of the executive management of the Cawnpoor terminal line was assumed by Lieutenant Hodgson, whose work has been executed at the following rates:—

	RS.	A.	P.	
First 20 miles	2	6	0	per 1,000 cubic feet.
31st to 65th mile	2	5	8¼	"

In excavating the escapes the rates for digging have been rs. 1-6-3 per 1,000 cubic feet; whilst those for the embankment works in connection with the Rindo have, from the nature of the works, which required consolidation, and the use of ramming and water, been as high as rs. 5-0-0 per 1,000 cubic feet.

IV. Etawah Terminal Line.

The excavation on this channel, the extreme dimensions of which are shown in the following diagrams, did not commence until 1850.

Diagram 174.

Section at the Head.

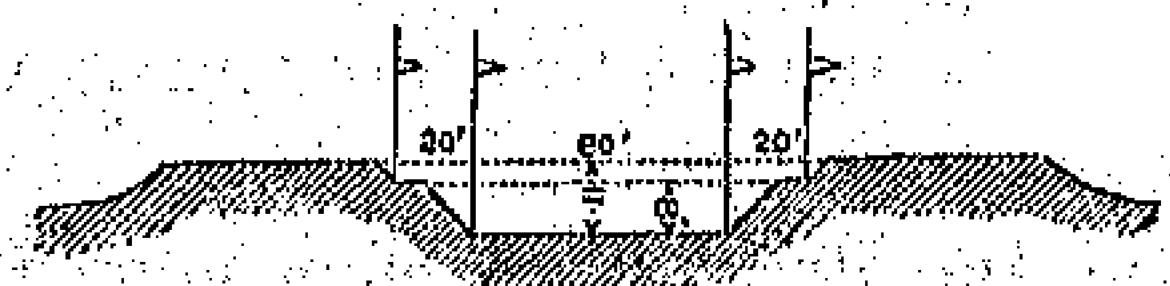
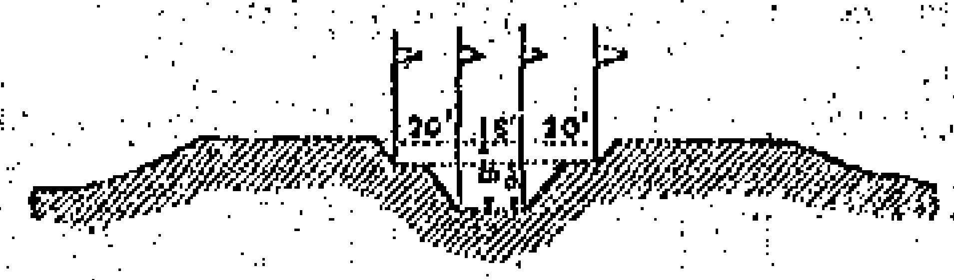


Diagram 175.

Section at the Tail.



The works, therefore, had the advantage of the experience that had been gained on the Cawnpoor line. The people in the neighbourhood were prepared in some measure for the system that would be adopted, as well as for the rates that would be allowed for excavation. The executive officer in charge, moreover, had had experience on the Jumna Canals. The rates which had been fixed in my estimate of 1850, were those which had been determined on by Lieutenants Hodgson and Hutchinson, viz., where the width of the rectangular channel was from,

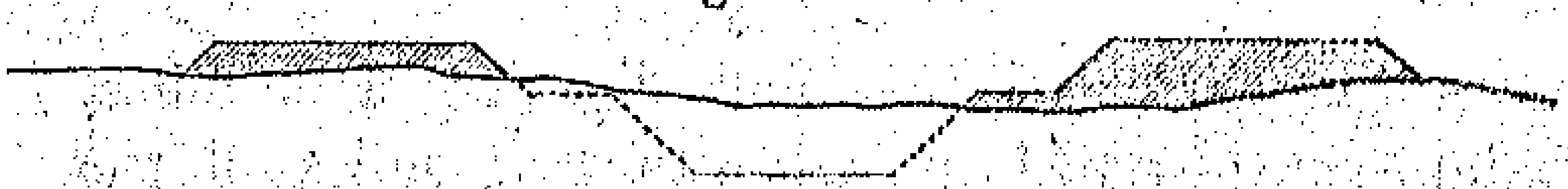
				RS.	A.	P.	
80	to	64½	at	1	14	0	per 1,000.
64½	to	40	at	1	10	0	"
40	to	20	at	1	6	0	"

It will be recollected that, for a distance of 65 miles, this line runs parallel to and within 5½ miles of the Cawnpoor terminal, and that in advance it proceeds through districts either bordering upon, or the same as those traversed by it. The rates of work might, therefore, be supposed to be the same. In the Etawah as on the Cawnpoor excavation, the rates fixed on appear to have been insufficient; every care has been taken to keep them as closely to the estimates as possible, and from what I have observed, I believe that, *cæteris paribus*, the rates at

which the work has been executed on these lines are very good specimens of the true cost of channel digging, limited to measurements of which the dimensions of the above sections are the extremes.

In laying out the *daghbels*, or lines upon which the excavation was made, it had been usual to fix wooden pins at distances, for the purpose of determining the level of the canal bed, of the berm, and also that of the embankments. These wooden pins were very subject to disarrangement, they were constantly knocked down by cattle, and were generally stolen by the village people. They were, moreover, after all, but an imperfect guide to the contractor. Lieutenant Whiting discarded the detached pins excepting for the bed levels, and at every 500 feet in length of the canal channel built up so much of the bank and berm as fell above the surface level of the country. This was made in the form of a rib, or former, so that at short distances along the whole line there existed previously to the commencement of excavation the true outline of the banks and berms as they were to be constructed at that particular point. Taking a section of the country upon which a contractor was set to work, its appearance was as follows:—

Diagram 176.



the shaded lines showing the rib or former, the dotted that portion of the work which had to be excavated. In proceeding down the line of works, therefore, where no excavators had been placed upon them, these ribs exhibited at a glance the amount of channel to be excavated, and showed clearly where the berms corresponded with the surface, or where embankments and raised towing-paths had to be made. In making these ribs or fixed

marks, a trifling expense was incurred in the first instance, and a good deal of supervision on the part of the surveyor; but they were amply compensated for afterwards by the facilities with which levels were recognized, and the method and order with which the whole work was done. I may observe that the pins which in former cases had been exposed were imbedded *in the earthwork of the rib*, so that the top of the pin acted as the true level or bench mark. The above plan originated with Lieutenant Whiting, and I consider it to be one well worthy of the consideration of those who may hereafter be engaged in canal excavation.

The berms, or towing-paths, are laid out on the same design as those described on the Cawnpoor Terminal, *i.e.*, with a few exceptional cases, they are parallel to the bed of the channel, and on a uniform scale throughout.

The soil is very similar to that described as existing on its sister branch to Cawnpoor. Tracts of oosur alternate with richly cultivated land, the latter predominating in the Etawah and Cawnpoor districts. Here also kunkur, both in mass, in gravel strata, and in pieces of the rock mixed indiscriminately with the soil, were met with in equal abundance. The soil, moreover, appears to have the same *non-absorbent* or *retentive* qualities that I have noted as so remarkable on the left of the Rinde River.

I have mentioned that the progress of excavation on the Etawah terminal line is more backward than elsewhere, in consequence of the lateness of the period at which it was commenced. On my last inspection, however, in December, 1853, the channel and embankments had been completed as far as the 60th mile, considerable advance had been made as far as the 110th mile, and work was in progress down to the 130th mile. Beyond this, no excavation had been commenced upon.

The *rates of excavation* are shown in the following table:—

Locality.	Rate per 1,000 cubic feet. rs. a. p.
From 1st to 20th mile	1 9 6
„ 20th to 40th „	1 9 3
„ 40th to 60th „	1 8 8

In looking at the rates and difficulties of procuring labourers on the terminal lines, especially that one bearing upon Cawnpoor; in recurring also to the observations made by the engineers on the remunerative value of the excavation to the contractors, in wide over narrow channels, where, although the rectangular digging in the one is much greater than that in the other, the slopes, embanking, and the more expensive parts of the work, are common to both;—I will, in concluding this chapter, remark, that in the channel excavations of the Eastern Jumna Canal, three-fourths of which were done by me between the years 1825 and 1830, partly by contract and partly by daily labour; the former being undertaken in most cases by the Oade tribes; the latter (which was only carried on in the immediate neighbourhood of my own or the European supervisor's encampment) by the labourers of the villages close at hand;—the rates were as follow, and they were determined by the superintendent of the works on the *nature of the soil*, and on *the facilities for excavation*, without any reference to dimensions. Where the soil was sand (although the channel was wider) the rate was lower than that where the digging was executed in clay. For instance, the fixed rates of contract were, from the village of Surkurri to the Jumna at Delhi (a distance of 111 miles), the rectangular width of channel at the two extremes being 30 and 15 feet,—rs. 1-8-0 per 1,000 cubic feet. From Surkurri upwards, where there was nothing but sand, although the rectangular channel varied from 30

to 60 feet in width, the rates were diminished to rs. 1-4-0 per 1,000 cubic feet; nor were these rates exceeded in the daily labour. These contracts included the making and forming of the embankments, berms, and slopes, and no contractor's accounts were settled until his full contract, which equalled 1,000 feet in length, was completed, and accepted as such by the European supervisor. This low rate of rs. 1-4-0, was even extended up to the Nyashuhur regulator, and through at least 4 miles of shingle digging.

I believe that in both these cases it would have been cheaper to have paid double the money, and to have done the work either by daily labour, or by employing more supervisors, to have had a greater check upon the contractors. It was quite impossible where the soil was hard, and where it came out of the excavators' hands in lumps, to get the lumps beaten up so that the embankments might be properly made. It was wonderful, the ingenuity with which bad work was concealed by a superficial coating of well-broken-up soil. But it was by no means wonderful to see the effect that this bad work had on our after prospects. Beautifully perfect as the section appeared when given over by the contractors, rainy season after rainy season produced its effects in exposing the hollowness of the work. It is a fact, that those banks which are now in such excellent order, and which offer one of the best roads and the pleasantest drives or rides in these provinces, were ten years before they were properly consolidated, and free from the annoyances of holes. The Ganges Canal embankments and earthwork may have been more expensive in the first cost, but eventually they will be cheaper in every respect than those of the Eastern Jumna.

CHAPTER XI.

CURRENT EXPENSES.

THIS chapter may be divided into two sections, viz.:—

I. Establishment.

II. Ordinary Repairs.

I. *Establishment.*

The detail of establishments as specified in Appendix D (*vide* Volume of Tables) was very closely observed during the whole of the operations. Where this was departed from, circumstances of a peculiar nature may be traced, as in the Northern Division, where the constantly increasing amount of works rendered increase of accountants necessary; and in the Second Division, where, from want of assistance to the executive, and the necessity for his time being occupied more than usual in field duties, a more highly paid, and more efficient head to his office became necessary. The rules, however, laid down in the above table were maintained as closely as possible, and the amount of establishment then fixed was considered to be the standard in each division.

The state of the establishments during the working period may be understood from the following tables, which show in juxtaposition the number of men and amount of pay of each which existed on the 1st of January, 1848, and the 1st of January, 1854; viz., on

the dates exhibiting the two extremes of the working operations, under my superintendence.

NORTHERN DIVISION.—1st *January*, 1848.

No.	Description.	Rate.	Amounts.	Total.
	WORKS.	Rs. a.	Rs. a.	Rs. a.
1	Executive Engineer	...	400 0	
1	Assistant	...	400 0	
2	Do.	250 0	500 0	
1	Do.	...	200 0	
2	Assistant Overseers	65 0	130 0	
1	Accountant	...	100 0	
1	Clerk	...	45 0	
1	Do.	...	40 0	
1	Do.	...	25 0	
				1,840 0
1	Native Surveyor	...	30 0	
1	Moonshi	...	30 0	
1	Treasurer	...	20 0	
2	Sowars	15 0	30 0	
3	Duffadars	6 0	18 0	
12	Burkandauzes	4 0	48 0	
3	Chuprassies	5 0	15 0	
4	Classies	4 0	16 0	
				207 0
1	Bricklayer Mistri	...	20 0	
1	Carpenter do.	...	14 0	
1	Smith do.	...	12 0	
				46 0
1	Moonshi	...	10 0	
1	Do.	...	9 0	
1	Do.	...	8 0	
1	Do.	...	7 0	
4	Chuprassies	5 0	20 0	
1	Do.	...	4 0	
				58 0
	Total Co.'s Rs.			2,151 0
	MATERIALS.			
1	Executive Officer	...	300 0	
4	Assistant Overseers	65 0	260 0	
1	Accountant	...	100 0	
1	Clerk	...	45 0	
				705 0
	Carried forward Co.'s Rs.			705 0

NORTHERN DIVISION.—*1st January*, 1818.—*Continued.*

No.	Description.	Rate.	Amounts.	Total.
		Rs. a.	Rs. a.	Rs. a.
	Brought forward Co.'s Rs.	...	...	705 0
1	Moonshi	...	30 0	
2	Duffadars	6 0	12 0	
8	Burkandauzes	4 0	32 0	
2	Moonshees	10 0	20 0	
2	Do.	8 0	16 0	
4	Chuprassies	5 0	20 0	
2	Do.	4 0	8 0	
				138 0
	Total Co.'s Rs.			843 0

NORTHERN DIVISION.—*1st January*, 1851.

No.	Description.	Rate.	Amounts.	Total.
	WORKS.	Rs. a.	Rs. a.	Rs. a.
1	Executive Engineer	...	600 0	
3	Deputy Superintendents	400 0	1,200 0	
1	Do. do.	...	300 0	
2	Do. do.	200 0	400 0	
3	Assistant Overseers	65 0	195 0	
1	Head Clerk	...	150 0	
1	Accountant	...	120 0	
1	Clerk	...	80 0	
1	Do.	...	60 0	
1	Librarian	...	20 0	
				3,125 0
1	Native Surveyor	...	30 0	
1	Moonshi	...	30 0	
1	Treasurer	...	20 0	
1	Assistant do.	...	10 0	
2	Sowars	15 0	30 0	
4	Duffadars	6 0	24 0	
16	Burkandauzes	4 0	64 0	
2	Chuprassies	6 0	12 0	
2	Do.	5 0	10 0	
4	Classies	4 0	16 0	
1	Chokidar	...	4 8	
1	Do.	...	4 0	
				251 8
	Carried forward Co.'s Rs.			3,376 8

NORTHERN DIVISION.—*1st January*, 1854.—*Continued.*

No.	Description.	Rate		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs	a.
	Brought forward Co.'s Rs.	...		...		3,379	8
1	Bricklayer Mistri	...		...		25	0
6	Moonshees	10	0	60	0		
7	Chuprassies	5	0	35	0		
						95	0
	Total Co.'s Rs.					3,499	8
	MATERIALS.						
1	Executive Officer	...		300	0		
4	Assistant Overseers	65	0	260	0		
1	Accountant	...		100	0		
1	Clerk	...		45	0		
						705	0
1	Moonshi	...		30	0		
1	Treasurer	...		20	0		
5	Moonshees	10	0	50	0		
2	Duffadars	6	0	12	0		
2	Do.	5	0	10	0		
14	Burkandauzes	4	0	56	0		
1	Chuprassi	6	0	6	0		
6	Do.	5	0	30	0		
						214	0
	Total Co.'s Rs.					919	0

SECOND DIVISION.—*1st January*, 1848.

No.	*Description.*	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
1	Executive Engineer	...		400	0		
1	Assistant do.	...		250	0		
1	Do. do.	...		200	0		
2	Assistant Overseers	65	0	130	0		
1	Accountant	...		100	0		
1	Clerk	...		45	0		
						1,125	0
	Carried forward Co.'s Rs.					1,125	0

SECOND DIVISION.—1st *January*, 1848.—*Continued.*

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
	Brought forward Co.'s Rs.	...		...		1,125	0
1	Moonshi	...		30	0		
1	Native Surveyor	...		20	0		
1	Do. Doctor	...		15	0		
2	Sowars	15	0	30	0		
2	Duffadars	6	0	12	0		
20	Burkandauzes	4	0	80	0		
1	Chuprassi	...		6	0		
2	Do.	5	0	10	0		
4	Classies	4	0	16	0		
1	Treasurer	...		20	0		
1	Assistant Treasurer	...		10	0		
						249	0
1	Bricklayer Mistri	...		15	0		
1	Do. do.	...		10	0		
1	Carpenter do.	...		12	0		
1	Smith do.	...		12	0		
						49	0
4	Moonshees	10	0	40	0		
4	Chuprassies	5	0	20	0		
						60	0
	Total Co.'s Rs.					1,483	0

SECOND DIVISION.—1st *January*, 1854.

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
1	Executive Officer	...		500	0		
1	Deputy Superintendent	...		200	0		
1	Acting do.	...		220	0		
1	Overseer	...		85	0		
3	Assistant Overseers	65	0	195	0		
1	Accountant	...		150	0		
1	Clerk	...		55	0		
1	Do.	...		25	0		
						1,430	0
	Carried forward Co.'s Rs.					1,430	0

SECOND DIVISION.—1*st January*, 1854.—*Continued.*

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
	Brought forward Co.'s Rs.	...		...		1,430	0
1	Moonshi	30	0	30	0		
1	*Assistant* Moonshi	...		10	0		
1	Native Doctor	...		15	0		
1	Treasurer	...		20	0		
1	Assistant Treasurer	...		10	0		
2	Sowars	15	0	30	0		
2	Duffadars	6	0	12	0		
20	Burkandauzes	4	0	80	0		
1	Chuprassi	...		6	0		
2	Do.	5	0	10	0		
4	Classies	4	0	16	0		
						239	0
1	Bricklayer Mistri	...		15	0		
1	Do. do.	...		10	0		
1	Carpenter do.	...		12	0		
1	Smith do.	...		15	0		
						52	0
6	Moonshies	10	0	60	0		
7	Chuprassies	5	0	35	0		
4	Duffadars	6	0	24	0		
24	Burkandauzes	4	0	96	0		
						215	0
	Total Co.'s Rs.					1,936	0

THIRD DIVISION.—1*st January*, 1848.

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
1	Executive Officer	...		400	0		
2	Assistants	200	0	400	0		
1	Clerk	...		40	0		
						840	0
2	Native Surveyors	10	0	20	0		
1	Moonshi	...		20	0		
2	Sowars	15	0	30	0		
1	Duffadar	6	0	6	0		
	Carried forward Co.'s Rs.			76	0	840	0

THIRD DIVISION.—1st *January*, 1848.—*Continued.*

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
	Brought forward Co.'s Rs.	...		76	0	840	0
1	Duffadar	...		5	0		
7	Burkandauzes	4	0	28	0		
1	Moonshi	...		8	0		
2	Classies	5	0	10	0		
2	Do.	4	0	8	0		
						135	0
	Total Co.'s Rs.					975	0

THIRD DIVISION.—1st *January*, 1854.

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
1	Executive Officer	...		500	0		
1	Deputy Superintendent	...		300	0		
1	Do. do.	...		100	0		
2	Assistant Overseers	65	0	130	0		
1	Accountant	...		80	0		
1	Clerk	...		50	0		
1	Do.	...		40	0		
						1,200	0
1	Native Surveyor	...		25	0		
1	Moonshi	...		30	0		
1	Treasurer	...		20	0		
1	Assistant Treasurer	...		10	0		
1	Native Doctor	...		15	0		
2	Sowars	15	0	30	0		
1	Jemadar	...		8	0		
2	Duffadars	6	0	12	0		
20	Burkandauzes	4	0	80	0		
3	Chuprassies	5	0	15	0		
4	Classies	4	0	16	0		
						261	0
1	Bricklayer Mistri	...		15	0		
1	Do. do.	...		10	0		
1	Smith do.	...		15	0		
1	Carpenter	...		12	0		
						52	0
	Carried forward Co.'s Rs.					1,513	0

THIRD DIVISION.—1st *January*, 1854.—*Continued.*

No.	Description.	Rate.	Amounts.	Total.
		Rs. a.	Rs. a.	Rs. a.
	Brought forward Co.'s Rs. .	...	...	1,518 0
2	Moonshies . . .	10 0	20 0	
2	*Chuprassies* . . .	5 0	10 0	
2	Burkandauzes . . .	5 0	10 0	
6	Do. . . .	4 0	24 0	
				64 0
	Total Co.'s Rs.			1,577 0

CAWNPOOR TERMINAL LINE.—1st *January*, 1848.

FOURTH DIVISION.

No	Description.	Rate.	Amounts.	Total.	Grand Total.
		Rs a.	Rs. a.	Rs. a.	Rs. a.
1	Executive Engineer .	...	400 0		
1	Assistant . . .	...	200 0		
1	Clerk . . .	...	45 0		
				645 0	
1	Native Leveller .	...	20 0		
2	Sowars . . .	15 0	30 0		
1	Duffadar . . .	...	6 0		
1	Do. . . .	...	5 0		
7	Burkandauzes . .	4 0	28 0		
2	Chuprassies . .	5 0	10 0		
1	Do. . .	4 0	4 0		
				103 0	
1	Carpenter Mistri .	...	10 0		
2	Mason do. .	8 0	16 0		
				26 0	
					774 0

SIXTH DIVISION.

No	Description.	Rate.	Amounts.	Total.	Grand Total.
1	Executive Engineer .	...	400 0		
1	Assistant . . .	...	200 0		
1	Acting Assistant .	...	220 0		
1	Clerk . . .	...	45 0		
				865 0	
	Carried forward Co.'s Rs. . .			865 0	774 0

CAWNPOOR TERMINAL LINE.—1st *January*, 1848.

SIXTH DIVISION.—*Continued.*

No.	Description.	Rate.	Amounts.	Total.	Grand Total.
		Rs. a	Rs. a.	Rs. a.	Rs. a.
	Bt. forward Co.'s Rs.	...	...	865 0	771 0
2	Native Levellers	10 0	20 0		
1	Moonshi	15 0	15 0		
2	Sowars	15 0	30 0		
1	Duffadar	...	6 0		
4	Burkandauzes	4 0	16 0		
1	Chuprassi	...	5 0		
2	Do.	4 0	8 0		
4	Classics	4 0	16 0		
				116 0	
1	Smith Mistri	...	12 0		
1	Carpenter do.	...	12 0		
1	Mason do.	...	12 0		
				36 0	
1	Moonshi	...	10 0		
2	Chuprassies	5 0	10 0		
	Duffadars	...	...		
4	Burkandauzes	4 0	16 0		
				36 0	
					1,053 0
	Total Co.'s Rs.				1,827 0

CAWNPOOR TERMINAL LINE.—1st *January*, 1854.

FOURTH AND SIXTH DIVISIONS AFTER AMALGAMATION UNDER THE DESIGNATION OF THE FOURTH DIVISION.

No.	Description.	Rate.	Amounts.	Total.
		Rs. a.	Rs. a.	Rs. a.
1	Executive Engineer	...	600 0	
2	Deputy Superintendents	200 0	400 0	
1	Do. do.	...	150 0	
2	Sub-Assist. Civil Engineers	100 0	200 0	
5	Assistant Overseers	65 0	325 0	
	Carried forward Co.'s Rs.		1,675 0	

CAWNPOOR TERMINAL LINE.—1*st January*, 1854.

FOURTH AND SIXTH DIVISIONS AFTER AMALGAMATION UNDER THE DESIGNATION OF THE FOURTH DIVISION.—*Continued.*

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
	Brought forward Co.'s Rs.	...		1,675	0		
1	Accountant	...		60	0		
1	Clerk	...		45	0		
1	Do.	...		25	0		
1	Do.	...		20	0		
						1,825	0
2	Native Levellers	20	0	40	0		
2	Do.	16	0	32	0		
1	Moonshi	...		15	0		
1	Do.	...		12	0		
1	*Native Doctor*	...		15	0		
2	Sowars	15	0	30	0		
1	Treasurer	...		12	0		
1	Jemadar	...		8	0		
2	Duffadars	6	0	12	0		
20	Burkandauzes	4	0	80	0		
1	Chuprassi	...		6	0		
2	Do.	4	0	8	0		
						270	0
1	Carpenter Mistri	...		16	0		
1	Mason do.	...		15	0		
1	Do. do.	...		8	0		
						39	0
7	Moonshees	10	0	70	0		
2	Do.	8	0	16	0		
13	Chuprassies	5	0	65	0		
2	Do.	4	8	9	0		
4	Do.	4	0	16	0		
9	Duffadars	5	0	45	0		
27	Burkandauzes	4	0	108	0		
						329	0
	Total Co.'s Rs.					2,463	0

ETAWAH TERMINAL LINE.—1*st January*, 1848.

FIFTH DIVISION.

	None.			

ETAWAH TERMINAL LINE,—*1st January*, 1854.

FIFTH DIVISION.

No.	Description.	Rate.		Amounts.		Total.	
		Rs.	a.	Rs.	a.	Rs.	a.
1	Executive Engineer	...		600	0		
3	Deputy Superintendents	200	0	600	0		
3	Assistant Overseers	65	0	195	0		
1	Accountant	...		80	0		
1	Clerk	...		45	0		
1	Do.	...		25	0		
						1,545	0
1	Moonshi	...		30	0		
1	Do.	...		15	0		
2	*Native Levellers*	20	0	40	0		
1	Do. Doctor	...		15	0		
2	Sowars	15	0	30	0		
1	Treasurer	...		20	0		
2	Jemadars	8	0	16	0		
5	Duffadars	6	0	30	0		
3	Do.	5	0	15	0		
41	Burkandauzes	4	0	164	0		
6	Moonshees	10	0	60	0		
1	Chuprassi	...		6	0		
13	Do.	5	0	65	0		
4	*Classies*	4	0	16	0		
						522	0
1	Carpenter Mistri	...		15	0		
1	Mason do.	...		12	0		
						27	0
	Total Co.'s Rs.					2,094	0

The establishment shown in the above table for the fourth and sixth divisions on the 1st of January, 1854, is that which was found to be sufficient after the amalgamation of these divisions, and after the whole line constituting the Cawnpoor Terminal had been placed in charge of Lieutenant Hodgson, of the Engineers. An inspection of the table will show that the reduction chiefly consisted in office establishment.

It will be understood that the establishments above referred to were dependent entirely on the progress and

completion of the works, as well as on the amount of work in hand, and that when this work was completed, and the canal channel had received water, an entire revision, not only of the establishments themselves, but of the divisions or districts connected with irrigation, would necessarily follow.

In arranging for the extent of divisions over which executive officers had control, during the progress of works, attention was directed to the magnitude and extent of these works, to keeping the duties of each executive as compact as possible, and to other circumstances of a local nature which at the time presented themselves. On the introduction of water, however, and the commencement of its distribution amongst the irrigators, there were other points to be attended to. It was considered advisable so to regulate the lengths of the districts, that each executive should possess the power of regulating his supply of water, and of holding in his own hands the means of obtaining relief to a certain extent from floods arising from excess of water in the canal, either from rain, or from diminution of irrigation in parts of the canal above his district.

To effect this purpose, it was determined that a leading feature in the arrangements should be the possession of an escape at the head of each district, and that a line of elective telegraph should as early as possible be carried from the Nanoon Fork, situated at the heads of the Cawnpoor and Etawah Terminal lines, along the canal bank to Roorkee, and the Myapoor Regulator. By these means it was supposed that each district would in itself have the power of obtaining relief by the escape at the head, and along the course of its own channel, whilst the electric telegraph would enable the officer to correspond with the districts lying above him, and with the dams and escapes in the northern regions. Ultimately,

wires connected with the electric telegraph reading office might be carried along each of the terminal lines, by which means the whole of the works from the head to the termini would be in *correspondence*. This design, if worked out *in extenso*, would undoubtedly place the whole machine in a very efficient state. It appears to me to be indispensable as far as the telegraph between Nanoon and the Myapoor head is concerned; as by no establishment that we could devise, would it be possible to protect ourselves against the inconvenience of high floods with such certainty, or with such immediate effect, as we could by a well-regulated telegraph.

The proposed limits of the different divisional districts for the Ganges Canal, when the water has been fairly admitted, and the rajbuhas sufficiently advanced to enable the cultivators to commence irrigation, may be thus given, as a sketch of what I would recommend in the early state of progress.

THE FIRST OR NORTHERN DIVISION.

The district attached to this division will extend from the Ganges River at the point where the canal leaves it to the Futtigurh branch head. Its total length is 50 miles, and it will, independently of the executive charge of the works, embrace the control of the whole of the irrigation in the Khadir, as well as that connected with the rajbuha heads at the Assoffnuggur, Muhmoodpoor, Belra, and Jaoli Falls. This district will be under the charge of an executive officer, who, under the title of "Superintendent of the Northern District," will act in the same capacity as the superintendent of the Eastern or Western Jumna Canals. He will have under his charge the whole of the works, and the control of the canal revenue within his boundaries. His duties, in fact, will correspond with those of the officers above mentioned, being responsible

both for the permanent works of the canal itself, for the efficiency of the rajbuhas, and for the proper supervision of the water rent. He will annually submit to the superintendent of canals, North Western Provinces, the same papers in abstract of the expenditure and receipts, with a balance-sheet of gross and net returns, with reference to dead stock and dues to Government.

The head-quarters of the superintendent will be at Roorkee, and he will have attached to him two deputies, one of whom will be specifically placed on the tract north of Roorkee. The other will have under his charge the works and irrigation on the high land stretching from Roorkee to the Futtigurh branch head. The duties of these two deputies will possess sufficient variety to enable the superintendent to form his own selection, founded on the qualifications of the officer. The leading or first subdivision, being that which is confined to the Khadir, will, comparatively speaking, be more connected with works than irrigation. Whereas that lying below Roorkee will have more of the latter than the former. The duties of both sub-divisions, however, are sufficiently mixed up with irrigation to qualify an officer for canal revenue duties, a point that I consider to be of great importance in a department, where the removal of officers from one post to another is of constant occurrence, and where a knowledge of revenue matters as regards canal irrigation is as indispensable as acquirements in civil engineering.

In addition to the superintendent and his two deputies, Mr. Finn, who during the progress of the works has conducted the material department, will retain his situation, with the additional duties of superintending the navigation in the Khadir. The object of these double duties is, as regards materials, to maintain at the different works a large supply of bricks in store. This can be done gradually, by keeping the village puzawas or

native brick-kilns in constant progress until a sufficient quantity of material has been collected. With reference to navigation, Mr. Finn will superintend the lockage and the boating between the head and the Solani Aqueduct. During the early periods, after the water is admitted into the canal, active measures will be required to transport boulders or river stone, for the purpose of laying down the flooring of the earthen portion of the Solani Aqueduct. It will be understood, from what has been said in Chapter IX., that the carriage of boulders to the above point *previously* to the admission of water was considered to be premature, and that vast expense would be saved by its postponement until the line was open for boats, by means of which a larger and better sort of boulder would be procured from the main Ganges and its branches than could be forthcoming from the mountain passes of the Sewaliks. The early completion of these boulder floorings is further indispensable for the satisfactory protection of the earthen part of the aqueduct from the wear and tear of the current. The deputation of Mr. Finn to the especial charge of this duty appeared to me not only to be likely to accelerate progress, but the employment itself was in a great measure allied to that in which he has given so much satisfaction previously. The step of placing the navigation under the especial management of an officer was a guarantee for its proceeding on a proper footing, and was the best means I could think of for establishing in the minds of the native community the advantages that were open to the trader from making use of the water for transport. I believe that a few years of steady progress in the use of the navigable canal and its lockage on the line between Hurdwar and Roorkee, will be in all probability the certain way of ensuring the ready adoption of the canal as a navigable line elsewhere.

Including Mr. Finn and his establishment in that of the northern district, therefore, the following is the design of the permanent establishment that might be considered appropriate:—

Northern District.

One superintendent; two deputy superintendents.

Deputy Superintendent, 1st Sub-Division. — Head-quarters at Roorkee, but liable to be detached to Hurdwar or any point between that and Roorkee.

WORKS.—Four overseers, of whom one at Myapoor, with a party of four tindals and forty beldars, in charge of dam and regulator, and of the canal banks from the main Ganges to the Jowallapoor Bridge. One at the Puttri, with a party of four tindals and forty beldars, in charge of the works and embankments lying between the Jowallapoor Bridge and the up-stream extremity of the Dhunowri revetments. One at Dhunowri, with a party of four tindals and forty beldars, in charge of the dam and regulator, and of the canal works and embankments, from the up-stream extremity of the Dhunowri revetments to the up-stream extremity of the Solani Aqueduct. One at Roorkee, with eight tindals and eighty beldars, in charge of the aqueduct and embankments; with further charge of "plant" attached to the works, including boats, horses, waggons, railroad, &c. This overseer would also be employed in the station of Roorkee, on the public buildings, and in the conservancy department.

Deputy Superintendent, 2nd Sub-Division. — Head-quarters at Roorkee, but liable to be detached to any convenient post between Roorkee and the Futtigurh branch head.

WORKS.—One overseer, who would be detached to either Bailra or Jaoli, so as to be in the vicinity of the works at the southern extremity of the district, with one tindal, and ten beldars, over each of the falls: viz., those at Assoffnuggur, Mulmoodpoor, Belra, and Jaoli, giving a total of four tindals and forty beldars.

I may observe with reference to these permanent beldar establishments, that I would consider them as entirely probationary. In the Khadir and north of Roorkee, where the population is small, and where the regulating arrangements at Myapoor and Dhunowri

render the presence of a skilled establishment indispensable, these establishments may possibly be of the utmost importance to the efficiency of the works. South of Roorkee, however, the necessity of maintaining large and expensive bodies of men may be questionable. In the early periods of the flowing of the water they may be useful; and, under this view of the case, it strikes me that they may be recommended, subject to after revisions, dependent on the experience gained by dealing with the running water.

Executive Officer of Materials and Superintendent of Navigation.—Mr. Finn, with a party sufficient for working the locks and maintaining the navigable canal in an efficient state for the passage of the craft. Mr. Finn's office and other establishment I would leave as it is at present; reducing it as opportunity offered, and as a necessity for so doing arose from actual experience.

I would say the same of the office and establishment of the superintendent or executive officer. A number of chuprassies and subordinate people would necessarily be discharged on the completion of the works. There could not possibly be any use for so great a number as there are at present. The office which now exists was raised for a specific purpose at periods when the accounts and responsibilities of the executive officer were enormous. This part of the establishment I would place on the same footing as it was originally, as shown in the list for January, 1848. That list, in fact, would be the scale upon which the whole permanent establishment of the division might be reorganized.

The revenue establishment must necessarily be regulated by the new code upon which Captain Baird Smith is now engaged, the details of which will greatly modify the existing scale, as practised on the Jumna Canals. In the meantime, however, I should consider that a

Zilladar and a Naib Zilladar for each 50 miles, and a Daroga for every 100 miles in length of canal irrigation, might be sufficient. The establishment for collecting would be regulated by that now existing elsewhere, with chokidars at each of the choki posts.

Under the above plan, therefore, the scale for the European establishment would be as follows:—

One superintendent of the district; two deputies; five overseers. One executive officer of materials and superintendent of navigation, in the person of Mr. Finn.

SECOND DIVISION.

The district attached to this division would extend from the Futtigurh branch head on the main line to the head of the navigable cut at the Bhola Falls, situated immediately above the Janni Khoord escape. It would not include any of the Bhola masonry works within its limits. The whole of the Futtigurh branch would be included in the second division, which would therefore consist of 33 miles of main canal in addition to the Futtigurh branch. The means of regulating the supply in this division, as far as rests with itself, depend on the Futtigurh branch, which lies at its immediate head, and on the Khutowli and Aboo's Nulla escape, which are situated at the 62nd and 69th miles. The close proximity to the Northern Division, however, gives this district great advantages in correspondence with the dams in the Khadir, the lowest of which—viz., that at the Rutmoo—is situated 38 miles north of the Futtigurh regulators.

At the time that I am writing, the Futtigurh branch has not been excavated: on its completion would depend the future scale of establishment for the division. In the meantime, however, I would lay down the same rules here as I have done for the northern district, viz.,

to adopt the scale of 1848, revising it to any extent that may appear applicable to the particular circumstances of the case. With regard to revenue establishment, it might be confined within the limit which practical experience has shown to be efficient on the Jumna Canals. The supervising establishment might be regulated as follows:—One superintendent of the district; three deputies; four overseers. The district to be divided into three sub-divisions, as follows: One deputy in charge of the main line of the canal from the regulating head to the navigable head and rajbuha of the Bhola Falls, with one overseer attached. This deputy would have charge of the regulating heads at Jaoli, with a working establishment on the following scale for the gates:—Four tindals; forty beldars. For the falls and locks at Chitowra and Sulawur, there would also be a working establishment consisting of one tindal and ten beldars over each work.

For the escapes at Khutowli and Aboo's Nulla, there would also be an establishment of one tindal and four beldars at each work.

These parties would be considered available for clearance of banks and all contingent demands in their neighbourhood, and I would recommend that, in defining the boundaries within which each party was to work, perfect order and tidiness within those limits should be insisted upon.

It will be seen that for the charge and management of the regulators, falls, and escapes, the above arrangement provides for an establishment of eight tindals and sixty-eight beldars, a party sufficient to do much useful work, if the men are properly looked after.

I look, however, with much jealousy on these permanent parties of beldars. Skilled men are undoubtedly required for working windlasses and managing the regu-

lation of water, but it may be questionable whether the object may not be gained at a smaller sacrifice of expenditure. My experience has convinced me that men of this description who are paid by the month do not work, either in excavation or clearance, equal to the daily-paid labourer. The permanent parties, however, secure the immediate attendance of labourers at critical moments, and in the early period after the admission of water, this may be a consideration in their favour.

The Futtigurh branch would, on its completion, engage the attention of two deputies and three overseers, with working establishments on the same scale for the falls and locks, escapes, &c., as I have proposed for the main canal. By the time, however, that this work is completed and supplied with water, sufficient experience will have been gained to render the scale of establishment required for its maintenance quite clear, without any speculative opinions being advanced at the present time.

Third Division.

The district attached to this division will extend from the head of the navigable cut at the Bhola Falls to the Kasimpoor escape and bridge, or from the 83rd to the 166th mile. It would include within its jurisdiction the Bolundshuhur and Koel branches to their confluence near the town of Hatrass, and it would terminate on the up-stream end of the Kasimpoor escape, with which work its superintendent would, however, have no control.

This district consists of 83 miles of the main canal, 90 miles of the Bolundshuhur, and 50 miles of the Koel branch.

At the present time neither the Bolundshuhur nor the Koel branches have been excavated. The working out of any organized system of establishment would depend on the completion of these works.

The Janni Khoord escape, which lies immediately at the head of the division, places the means of regulating head supply in the hands of the superintendent. Besides this leading escape, the Bolundshuhur and Koel branches give him further aid in the control and management of the water, and the Moonda Khera escape, which lies at the 143rd mile, enables him to relieve the canal in cases where the branches themselves may be overloaded. The means of escape in the third district appear to me to be well adapted to the circumstances under which it is placed.

For this division, there would be—one superintendent of the district; two deputies; four overseers. The district would be divided into two sub-divisions, each, as before, under a deputy superintendent.

The first sub-division would extend from the navigable head at the Bhola Falls to the up-stream end of the Moonda Khera escape and works, on the main line of canal, with the charge of the Bolundshuhur branch.

This deputy would have charge of the falls at Bhola and Dasna, as well as the management of the Bolundshuhur regulators. He would have two overseers under him, one for the special charge of the Janni Khoord escape and the Bhola Falls. For the former I would give the same working establishment as before noted, viz., one tindal and ten boldars for each of the falls; one tindal and four boldars for the Janni Khoord escape; and for the regulators I would give four tindals and forty boldars.

The second sub-division would extend from the Moonda Khera escape and works (including those works) to the end of the district or to the upper end of the Kasimpoor escape. The Koel branch would also be included in this sub-division.

This deputy would have charge of the Moonda Khera

escape, of the falls at Pulra and Simra, and of the regulators at the head of the Koel branch, with two overseers under him.

The working parties at the above works would be as follow:—

Moonda Khera Escape	1 Tindal. 4 Beldars
Falls at Pulra . . .	1 Tindal. 10 Beldars.
Ditto at Simra . .	1 Tindal. 10 Beldars.
Koel Regulators . .	3 Tindals. 30 Beldars.

I would make the conditions on which the maintenance of this permanent establishment rested, similar to those above described; the establishment of tindals and beldars as fixed establishment should, in fact, be experimental.

The superintendent's office and divisional establishment I would determine on the scale of 1848, revised agreeably to circumstances; and the revenue arrangements would be formed on the scale of the Jumna Canals —*i. e.* one daroga to each 100 miles in length of channel, and one Zilladar and one Naib Zilladar to every 50, with Chokidars at the different chokies, and subordinate establishment on the scale which has been found to answer elsewhere.

Fourth or Southern Division.

This district would include that part of the main canal extending from the Kasimpoor escape to Nanoon, or from the 166th to the 180th mile, in addition to the terminal lines running towards Cawnpoor and Etawah.

The Kasimpoor escape would be the leading regulator of the supply in this district. The escapes on the terminal lines and the regulating bridges at the heads

of the terminal lines would act subordinately for similar purposes.

The supervising establishment would consist of one superintendent of the district, four deputies, and seven overseers.

As this district is of a much greater extent than the others, especially in its connection with the Hatrass irrigation, I would classify the deputies under two heads, making one a first class on a higher salary of 300 rupees, and the remaining three, second class, on the usual salary of 200 rupees per month.

The first-class deputy should have immediate charge of the Kasimpoor escape and the Nanoon regulators, with the intermediate line of canal and its irrigation, under the denomination of the First Sub-Division.

The second-class deputies should hold sub-divisions, as follow :—

Second Sub-Division.—From the Nanoon regulators along both of the parallel lines of canal, extending to the bridges on the high road between Mynpoori and Etawah.

Third Sub-Division.—From the bridge on the Mynpoori and Etawah road on the Cawnpoor Terminal line to the end at Cawnpoor.

Fourth Sub-Division.—From the bridge on the Mynpoori and Etawah road on the Etawah Terminal line to the Jumna.

The first-class deputy in charge of the Nanoon regulators would have under him the following permanent working establishment :—

Kasimpoor Escape .	1 Tindal. 4 Beldars.
Nanoon Regulators .	2 Tindals. 20 Beldars.

The first-class deputy would, comparatively speaking, hold a sub-division of small extent, but he would be

available for more extended duties on the requisition of the superintendent.

I would here, as elsewhere, maintain the establishment of the fourth and fifth divisions on the scale of 1848, revising them to meet the nature of the supervision and work which experience might point out to be necessary.

For the revenue and management of irrigation, I believe that Captain Baird Smith's new code will be prepared long before water is brought with any regularity upon the Nanoon regulators, in which case the scale now adopted on the Jumna Canals for collection and irrigation establishment, and which I would recommend as a starting point here, would be superseded. It appears to me unnecessary, therefore, to speculate on the precise detail of subordinates that may be required hereafter. By adopting that which was in force in 1848, both as regards office and working establishment, a reasonable scale, upon which we can base any after modifications, appears to be provided.

Looking therefore to the statement for 1848, given in the early part of this chapter, as that which provides a scale for both the office and working establishment of each of the proposed districts, I may, in recapitulating the European establishment required for each, and the length of canal in miles which each superintendent has to control, give a distinct idea of the distribution of the executive, who, in direct correspondence with the superintendent-general, would supervise the works, and manage the irrigation of the Ganges Canal. I may, however, remark that, although, in the preceding details, as well as in the following summary, I have fixed the scale of number and grades of deputy superintendents at the lowest possible point, I am of opinion that it would add to the efficiency of this branch if it were to be understood that, in cases of high merit, each division might

have one first-class deputy, not of necessity, but as a stimulus to exertion, or reward for good work done.

SUPERINTENDENT-GENERAL.

1ST OR NORTHERN DISTRICT.

1 SUPERINTENDENT.

1st Sub-Division.—1 Deputy superintendent and 4 overseers. Above Roorkee, distance 19 miles.

2nd Sub-Division.—1 Deputy superintendent and 1 overseer. Below Roorkee, distance 31 miles.

From the canal head to the Futtigurh branch head, 50 miles.

1 Executive officer of materials and superintendent of navigation from canal head to Roorkee.

2ND OR JAOLI (UPPER CENTRICAL) DISTRICT.

1 SUPERINTENDENT.

1st Sub-Division.—1 Deputy superintendent and 1 overseer, in charge of regulating heads and main line of canal to the navigable head at the Bhola Falls, 33 miles.

2nd Sub-Division.—The Futtigurh branch, in which 2 deputies and 3 overseers would be employed, 165 miles.

Total length of district:—

Main	33	miles.
Branch	165	,,
Total	198	,,

3RD OR BOLUNDSHUHUR (LOWER CENTRICAL) DISTRICT.

1 SUPERINTENDENT.

1st Sub-Division.—1 Deputy superintendent, with 2 overseers. From the Bhola Falls to the up-stream end of the Moonda Khera escape, with charge of the Bolundshuhur branch, 150 miles.

2nd Sub-Division.—1 Deputy superintendent, with 2 overseers. From the up-stream end of the Moonda Khera escape to the up-stream end of the Kasimpoor escape, with the control of the Koel branch and its regulation; distance, 73 miles.

Length of district:—

Main line	83	miles.
Bolundshuhur branch	90	,,
Koel branch	50	,,
Total	223	,,

4TH OR TERMINAL DISTRICT.

1 SUPERINTENDENT.

1st Sub-Division.—1 First-class deputy superintendent, with 1 overseer. From the upper end of the Kasimpoor escape to the Nanoon fork, including the regulators at that point, 14 miles.

2nd Sub-Division.—1 Second-class deputy superintendent, with 2 overseers. From the Nanoon regulators to the Mynpoori and Etawah road on both terminal lines; distance, $70 \times 2 = 140$ miles.

3rd Sub-Division.—1 Second-class deputy superintendent, with 2 overseers. From the bridge on the Mynpoori and Etawah road, on the Cawnpoor Terminal line, to the Ganges at Cawnpoor, 100 miles.

4th Sub-Division.—1 Second-class deputy superintendent, with 2 overseers. From the bridge on the Mynpoori and Etawah road, on the Etawah Terminal line, to the Jumna, 105 miles.

Total length of district :—

Main line	14	miles.
Cawnpoor Terminal	170	„
Etawah do.	175	„
Total	359	„

The total number, therefore, of European officers required on the scale above laid down, independently of the superintendent-general, would be—

4 Superintendents of districts.
11 Deputy do. { 1 first class. 10 second class.
1 Executive officer of materials and superintendent of navigation.
20 Overseers.

With reference to the last item, I would by no means confine the class of men holding the situation of overseers to Europeans. Europeans, if selected and chosen for their qualifications in being quick at resources, or interested in the peculiar duties, on which, as canal overseers, they will be especially placed, are undoubtedly to be preferred. If, on the contrary, they are unselected, and placed upon the works as they have been during my superintendency, merely because they had passed a fair examination at the Roorkee College, I would sooner have natives. Europeans, in fact, unless they have qualifications which enable them to submit to the solitude of

detached district posts without repining; unless they are gifted with energy of character, and quickness at remedying, and even anticipating accidents, are, in nine cases out of ten, useless. Unsteadiness of character, whether arising from intemperance or neglect of duty, is absolutely ruinous to any works, with an active agent like that with which we have to deal constantly opposed to us. Running water won't wait upon the indifference of either sergeant or corporal; and a man who won't or can't mount his horse at any period of the night or day, to visit the extreme limits of his division, is utterly unfit for canal service. If Europeans are appointed to this duty, they ought to have horse allowance. I would give each man 20 rupees a month, or sufficient for the keep of two horses; and I would place such powers in the hands of the superintendent-general, that neither should this allowance be misapplied, nor should any European have the power of retaining his place one moment after he had either by drunkenness, or neglect, forfeited his claim to the confidence of the superintendent of the district. On the other hand, the superintendent-general ought to have the power of rewarding good conduct, and of promoting to a higher grade in the department those men who signalize themselves by meritorious conduct. To effect this, the establishment of overseers might be divided into three grades, each step giving an increase of salary. With regard to a choice between European and native in the situation of overseer, my opinion, after very nearly 30 years of canal service is, that a good European is invaluable. A bad one is not only worth nothing, but he is so expensive and troublesome, that his presence on the works is injurious to their interests, and in many cases he becomes absolutely dangerous from the natural tendency that exists to entrust him with orders, and to place confidence in his energy of character.

The native wants the energy of the European, and, generally speaking, does not carry with him weight sufficient to control his subordinates, but in other respects, he has attributes of a very high order, temperance, sobriety, knowledge of the people over whom he is placed, and very great intelligence. During my career I have certainly had less disappointment with natives than I have had with Europeans, a result which is probably arrived at from the former being more under control, and, as such, being more subject to summary punishment than the latter. The European when once appointed to the department can only be punished by suspension, subject to the orders of the Board, whose position in Calcutta, at a distance of a thousand miles, renders immediate retribution impossible. Removal from the department can only be effected by a reference by the Military Board to the head of the Supreme Government, so that what with one delay and another, I have known a man to remain under suspension for nine months, drawing pay and canal salary, before any orders were given as to his ultimate disposal. This acts both ways, the canal officer is restrained from bringing to the notice of his superiors acts which will lose him the service of the only man probably to whom he has to look for carrying on business, with little chance of a speedy settlement of the question at issue; the European overseer takes his measures accordingly, and if a bad man, is indifferent to results so fearfully procrastinated. This appears to me to require remedy.

In the canal department an assistant overseer when appointed either from the Civil Engineers' College at Roorkee, or direct from his regiment, joins the superintendent of a canal and is at once sent on detached duty. There, at a distance from society, with a control over native subordinates, and with a management of

works that ought properly to be entrusted to an experienced man only, the young overseer has to learn his duty as well as he can. He is selected from the Roorkee College without the slightest reference to his turn for building or civil engineering. His study at the college is of books only, and he reaches the department in which, as I have shown, he is immediately called upon to take up duties requiring knowledge and experience, as ignorant and as inexperienced as he could well be. Under such circumstances, can it be wondered at, that a young *raw barrack recruit goes wrong?* The *consequences are* fatal to the unfortunate man in numbers of instances, the government works suffer by all sorts of mistakes and blunders; and the executive engineer, who is held responsible for the cost and quality of work done, has literally nothing to do, but to look on and bear it. The remedy that I would propose is this, that men, when they have passed their examination at the college, should be drafted off in parties of from two to ten in number, and sent to the head-quarters of any department or division of public works, which was most extensively employed in building. The men should remain on probation actively employed on these works under the eye of the executive engineer or his assistants, and at the termination of two years, his retention in the department of public works at all should depend upon his efficiency as a builder, or as an overseer over buildings. The determination on these points should be guided by the report of the executive engineer under whom he has been probationarily employed. No assistant overseer ought to be sent on detached duty until he has passed through two years of probation in actual building under the eye of an officer.

The education of the European overseer at the present time, is confined to six or twelve months' reading at the Roorkee College. It is entirely theoretical. Previously

to admission he is called upon to pass an examination on the following subjects: reading, writing, arithmetic, as far as vulgar fractions, elementary geometry, mensuration, simple plan-drawing. He is passed out of the college by a process equally easy. He then commences a series of which I have attempted to give an explanation above. Now, why should not the period be extended to a further course of practical building at Roorkee, to an acquisition of knowledge on the different details of brick and mortar practice, as called for in the department of public works; to becoming acquainted with the native terms and expressions used in the profession that he is about to embrace; to a comprehension of the cost and value of work of different descriptions, and to the general details of matters that must eventually come before him? The second class of the college, which consists entirely of non-commissioned officers and men who are intended for the department of public works, might, it appears to me, have its standard of proficiency raised very greatly by some such modification of the present system. That this will be done eventually, or in its absence, that the two years of probationary service should be called for from each assistant overseer, I hope for with all my heart, not merely for the good of the service alone, but in justice to the young European, who, in the present state of things, is not fairly dealt with.

When a European enters the department without the ordeal of entering the Roorkee College, his qualifications are judged of by an examination carried on by a committee of engineer officers, the extent of which is a knowledge of arithmetic, mensuration, and an estimate of the cubic content and cost of a plain barrack building. In this case the man, on his entering the department of public works, is worse off than his contemporary from the Roorkee College. The last is educated and prepared in a

small degree, the former in nine cases out of ten has no education at all.

I believe that the deficiencies noted above are as patent to the public works in general, as they are to the canal department. In the latter, however, the posts of overseers are, with one solitary exception, *viz.* at Roorkee, detached from the eye of officers, and ought not to be trifled with. The men selected for those duties might with the greatest advantage to the State be better educated. They might be selected from those whose inclinations lead them to civil engineering as a pursuit, and not as a mere change from the routine of regimental duty.

Since the establishment of the Civil Engineers' College at Roorkee, and its division into three classes,—the first being for the more highly educated, and for those capable of being employed on the duties of sub-assistant civil engineers; the experiment has been tried of drafting students of this class into the canal department. Four of these young men were placed under the orders of executive engineers, and with the exception of one, who was removed for indolence and inefficiency, they have got on very well. Their duties have been confined to short sub-divisions of works, in which they have had to survey, lay out, and excavate canal channels, form embankments, and plant trees. They have also had to superintend masonry works, such as bridges, drain-heads, chokies, &c. For all these they have to draw out their own plans, copied from the office designs, to return measurements of cubic content of work, and to submit monthly accounts to the executive. There are two men of this description on the Cawnpoor terminal line, who have at the present time served five years. As far as I can gather from the reports of the officers under whom they serve, and from my annual inspections, the work done by these men is equal to that performed under

European superintendence, and as far as building and the correct finishing of buildings is concerned, better. The only want that this class of men has, is the active energy which the European naturally possesses. Madho Ram and Petumber Sing, the gentlemen to whom I allude above, have shown themselves highly deserving of the confidence of the executive engineer, and are good specimens of material which may ultimately be turned to excellent account in the department. The rate of pay of the sub-assistant civil engineer is 100 rupees per month, with allowance when marching equal to three-tenths of that salary.

The first class, which produces the sub-assistant civil engineer, is followed by the second class, which is especially devoted to non-commissioned officers and privates for education as overseers. In this class there is an uncovenanted department, which is also intended to supply the public works with overseers and supervisors. I have before remarked that great benefit would be derived from these men being made to undergo a series of practical studies on construction before they were allowed to be detached. That this should be done appears to me to be indispensable. Men of this class, moreover, should not leave the college until they had acquired a knowledge of the technicalities of the profession in which they are about to enter. They ought not only to speak the language freely, but to speak that language which would enable them to hold a conversation with the native mason, smith, and carpenter. They ought, at any rate, to know the native name for a brick, or for a brick-mould; information which many of the men now received in the Department of Public Works are altogether innocent of. Non-commissioned officers and privates, on their reaching Roorkee, ought not to forget that they are soldiers, and this ought to be

instilled into their minds during their education at the *college. Examples of an utter forgetfulness of military* discipline, or, I should rather say, discipline of any sort, are by no means uncommon; and rough reminders are *every now and then required, as disagreeable to the giver* as to the receiver, to bring to the soldier's mind that discipline is not dropped in the absence of the sergeant-major.

The third class at the Roorkee College is especially for the education of native surveyors, draughtsmen, &c. It is, in my opinion, the most useful division of the college. From hence are derived the numerous native levellers, surveyors, and draughtsmen, who are holding posts under the Road Committees, surveys, canals, &c. A hiatus has been filled up by the introduction of this class, which has long been the drag upon all progress. European agency was too costly. Exposure to the sun and climate was a bar to the indiscriminate employment of the European on many out-of-door duties, which are now readily filled up by the native; and as draughtsmen, the wonderful perseverance and delicacy of manipulation for which the native is incomparably superior to the common run of Europeans, render him invaluable either in mapping or plan-drawing; whilst the comparatively low rate at which the native can live in India, and the few wants which his position demands, makes his services available where the monthly pay of an European would be entirely prohibitory.

Native draughtsmen in the Director's Office, who have certainly had the advantage of the instruction and supervision of Mr. W. Marton, the head assistant, whose own acquirements as a draughtsman are of a very high order, do the whole of the work of copying and reducing that exists in that office. The execution of their work is equal to anything that could be desired,

and far superior to that of the common class of European who is available for this purpose in India. A salary of 200 rupees a month, or 240*l.* a year, was insufficient to secure a man of the latter class, with acquirements of a very ordinary description; whereas the highest salary in the Director's Office to the native draughtsman is 50 rupees a month, or 60*l.* a year. Many of the maps and plans figured in the Atlas which is attached to this volume, are done by either Kadirbuksh, Wujeeoodeen, or Luthfoola Khan, three of the leading men in the office, and for neatness of execution and wonderful accuracy of copying (neither one nor the other being acquainted with English any further than the written character) they would not fail in comparison with drawings done by Europeans holding five times their salary.

Native levellers and surveyors who are attached to the different executive officers, and who draw only from 15 to 25 rupees a month, carry on a great portion of the interior surveys and cross levels from bench mark to bench mark. They are invaluable in readily obtaining a small survey, or a rough configuration of country, previously to the designing of works, and they relieve the European officer from the exposure and constantly recurring labour, that previously to their introduction occupied a great portion of his time.

With the road committees, they are the means by which the alignements of roads are determined, and frequently in addition to the operations of survey and mapping, they take an active part in the execution of the works.

Although the third class in the Civil Engineers' College at Roorkee has now been in existence only for five years or thereabouts, it has passed out the following students, who have received employment as below:

Roads and department of Public Works . . .	6
Surveys, &c.	27
Canals and embankments	23

Besides having afforded education to numerous young men who have not been publicly provided for. It has, moreover, introduced an element of competition amongst the mootsuddi and lalla class, for which the neighbourhood of Roorkee is celebrated, which is likely to be exceedingly beneficial, not only in the department of public works, but in all departments connected with the general improvement of the country in works of public utility.

With reference to the subject of this chapter, therefore, it will be seen that the system of education now in force at Roorkee is likely to be of great aid to the canal department in general, and to all improvements where irrigation is concerned; that we may depend hereafter on an institution from whence we may derive men of three different classes to aid us in our progress; and that we shall not be, as heretofore, dependent entirely on our own individual exertions for every step of advance that is made towards improvement.

There are two points which, in closing this chapter, I may very properly draw attention to; the first is the nomenclature of appointments that now exists in the canal department; the second is the position that the chiefs of districts are to hold with regard to *residence*. These are questions which have up to the present time led to much confusion, and from the experience that I have had appear to me to require remedy. I shall, therefore, say a few words on each, taking them in the order of their precedence.

1st. *The Nomenclature of Appointments.*

Up to the period at which I am now writing, the chief authority in the canal department is entitled "Superintendent of Canals in the North-West Provinces, and Director of the Ganges Canal Works." The former being generally applicable to his control over the different canals

in the neighbourhood, and the latter specifically addressed to his proceedings in carrying out the works of the Ganges Canal.

Under the first head he has under him:—1st. The superintendent of canals west of the Jumna. 2nd. The superintendent of canals east of the Jumna. 3rd. The superintendent of canals in the Doon. 4th. The general superintendence of the works on the Nudjufgurh Jheel, the detail of which is specifically under the civil authorities at Delhi.

Under the second head he superintends the whole of the executive establishment of the works on the Ganges Canal, with the control of accounts, &c., the appointment being, as I said before, a specific one. To this there can be no objection, it depends upon the progress and carrying out of a very extensive Board of Works.

The confusion that now exists, arises from the term "Superintendent of Canals" being applicable to the chief as well as to the subordinates. They are all superintendents of canals. Laying aside the affix as applicable to the particular works upon which each officer is employed, there is no distinguishing mark to separate one from the other. This impression is not confined to the public, but it is exhibited in the Government general orders and the Office of the Military Board. My own appointment at this moment stands as follows:—

"Fort William, 31st March, 1848. No. 123 of 1848. Major Proby Thomas Cautley, of the Regiment of Artillery, who was directed in General Order No. 23, of the 14th January, 1848, to officiate, is appointed Director of the Ganges Canal, and Superintendent of Canals west of the Jumna, from the date on which Major Baker, of Engineers, proceeded to Europe on furlough;" the expression, "*Superintendent of Canals west of the Jumna,*" having been substituted for "*Superintendent of Canals,*

North-West Provinces," the appointment to which I succeeded on Major Baker's departure for Europe.

The executive engineers who carry on the works of the Ganges Canal are assisted by young officers bearing the designation of deputy superintendents. There is no uniformity at present in the nomenclature, a point that might be remedied without much difficulty.

As the canal department naturally embraces all works intended for the purpose of irrigation, I would call the chief by a name directly allied to the functions of his office, neither referring especially to canals, tanks, nor works of any specific description. A simple definition of the different grades might be as follows :—

Superintendent-General of Irrigation, North-Western Provinces; having under him :—1st. Superintendent of the Western Jumna Canal. 2nd. Superintendent of the Eastern Jumna Canals. 3rd. Superintendent of the Doon Canals. 4th. Superintendent of the Nudjufgurh Jheels. 5th. Superintendent of the Northern District Ganges Canal. 6th. Superintendent of the Upper Centrical District Ganges Canal. 7th. Superintendent of the Lower Centrical District Ganges Canal. 8th. Superintendent of the Terminal District Ganges Canal. Each of these officers having deputy superintendents under him, with a lower grade of sub-assistant civil engineers.

My present designation of "Superintendent of canals, North-West Provinces, and Director of the Ganges Canal Works," would merge into that of "Superintendent-General of Irrigation, North-West Provinces," whilst the executive chiefs would resolve themselves into superintendents, with their deputies and sub-assistant civil engineers. This would be a simple method of escaping from the confusion of names and titles that now exist.

2nd. *The place of Residence for Executive Chiefs or Superintendents of Districts.*

A fixed place of residence or head-quarters' station in each district over which an officer presides, is most especially called for. It is advocated by me most particularly on account of the regularity that attends on an office which, although called upon to make periodical moves, is provided with a permanent and fixed place of residence; on account of the efficiency of record and reference that attaches itself to fixed accommodation arranged for the purpose; and for the convenience of all who are connected with the irrigation of the district, in having a recognized public office, or court-house, to which they can go to transact business. I would, therefore, in each district of the Ganges Canal, determine on some centrical or most convenient point, at which a government building should be erected for the purposes of office, and for the repository of records. At this place the superintendent of the district should fix his head-quarters, and it ought to be made a part of the compact on which he holds the superintendency that he should reside not only at the station at which the public office is fixed, but in its immediate vicinity. As the accommodation required for the office and records at a head quarter station of this sort is not very extensive, it might perhaps with advantage be combined with residence for the superintendent of the district. This arrangement would determinately settle the question (on the Jumna canals at present an undecided as well as an uncertain one) as to where the head-quarters station was to be fixed. It would secure the proximity of the office to the presiding chief, and it would place the superintendents of districts on a par with those, the recognized responsibility of whose situation has made it desirable that the officer in charge should have a permanent residence.

The cost of an office building built of brick and mortar, that is to say, a permanent structure, sufficient for office purposes, may be estimated at 2,000 rupees, or *200l. sterling.*

The cost of a residence of an officer from whom 50 rupees a month would be deducted for public residence, allowing that 10 per cent. is sufficient interest for capital sunk in its construction, would be equal to 6,000 rupees.

Combining the two buildings under one roof, there would, on the above estimate, be an available sum of 8,000 rupees to expend on the public accommodation above alluded to. Additional outlay on offices might bring the total cost up to 10,000 rupees for each office and residence of superintendents of districts. For this expenditure there would be an immediate return of 600 rupees per annum in house-rent, plus the accommodation for the office and records.

The Ganges Canal works would require four of these public buildings, the total cost of which would be rs. 40,000. The sites of these buildings, which I would call first-class, would be as follow :—

1. Superintendent of Northern District at Roorkee.

2. Superintendent of Jaoli, or upper Centrical District at Jaoli.

3. Superintendent of Bolundshuhur, or lower Centrical District, on some elevated spot between Bolundshuhur and the canal.

4. Superintendent of Terminal District on some elevated spot between Mynpoori and the Terminal Lines.

The above plan would be a security for permanence of position to the chiefs of districts; and it would be economical, as well as leading to efficiency, to have the principle carried out in determining fixed posts for the deputies and overseers, so that every European officer attached to a district might be placed on a similar footing.

For this purpose, agreeably to the scale described early part of this chapter, we should requir buildings for deputies and twenty for overseapter, endea which at present can only be roughly determent th which, as irrigation developed itself, might be v satisfactorily fixed by the superintendent-general irrigation.

Allowing 10 per cent. as the return for capital ex pended in house property, and that a monthly deductio for house rent from a deputy superintendent of 25 rupees, and from an overseer of 8 rupees, might be fairly made, the outlay on each residence for the former would be rs. 3,000, and for the latter rs. 960; the total sum required being as follows: *eleven second-class residences for deputies at rs. 3,000 each, rs. 33,000; twenty third-class residences for overseers at rs. 960 each, rs. 19,200: total Co.'s rs. 52,200.*

In the Northern District the deputies would reside Roorkee, at which place there would be two seco st-clas residences. Five overseers' third-class residen posed to Myapoor, one at Puttri, one at Dhunowri, one ury falls and one at Muhmoodpoor. country

In the second district there would be three secon class residences. Two on the Futtigurh Branch, th position of which would be fixed hereafter, when the works are completed, and one at Sirdhunna: four over seers' third-class residences; three on the Futtigurh Branch and one at some intermediate point between the Futtigurh Head and the Bhola Falls, on the main line of canal.

In the third, or Bolundshuhur District, there wo be two second-class residences. One at Bolundshuh Branch Head, and one at Koel Branch Head: four over-seers' third-class residences; one on the Bolundshuhur Branch, the site to be fixed hereafter; one on the Koel Branch, the site to be hereafter fixed; the head of the

at Gungowli would probably be the best position; ...r near to the Janni Khoord escape, of which he ... specific charge; and one at some interme- ... between the Bolundshuhur Branch Road and ... Kasimpoor outlet on the main canal.

In the fourth or terminal district there would be four second-class residences. One at the Nanoon Regulators; one at some intermediate point between the Nanoon head and the high road between Mynpoori and Etawah; one at some intermediate point between the Mynpoori and Etawah Road and the Cawnpoor Terminus; one at some intermediate point between the Mynpoori and Etawah Road and the Etawah Terminus on the Jumna: seven overseers' third-class residences; one at the Kasimpoor escape head, of which he would have especial charge; and six at ——. The position of the residences of these men would be determined hereafter.

The advantages of an arrangement similar to that above proposed are manifold. In the first place it would ... on-residence, and secure to the canal works and ... settled supervision. In the second, it would ... ks of an evil which exists to a great extent on ... Jumna Canals, and which is ruinous in its effects to overseers, and even to officers if they enter upon it, viz., the building of private residences at detached and favourite spots, and a consequent loss of property on either a successor refusing to purchase, or on his being posted to another locality. I consider that by providing the whole of the European establishment with public residence (for which it must be recollected the State would receive fair interest in house-rent), the Canal Department would be relieved from one of its greatest interruptions in the want of permanence in the disposition of its European subordinates.

Section II.—Ordinary Repairs.

I have in the first section of this chapter endeavoured to give an outline of the establishment that may be required for the maintenance of the works and supervising the irrigation. I will now enter upon the ordinary repairs or the probable annual cost that will be entailed upon the Government for keeping the works in efficient repair.

In estimating this amount, we must take into consideration the large masses of water with which we shall be called upon to deal, the great extent of building that exists in the Khadir tract above Roorkee, and the general character of the Ganges Canal, so different from all works for irrigation in these provinces. The Western Jumna Canals, the difficulties of which as regards slope of bed are overcome by a tortuous course running along the natural beds of rivers, offers no analogy to that of the present work. We naturally therefore look to the Eastern Jumna Canal, where the numerous dams opposed to mountain torrents, and the multitude of masonry falls or descents to overcome the natural slope of the country, present, although in a comparatively small degree, features by which we may be guided in arriving at an estimate of the annual expenditure required on the Ganges Canal Works.

There are two ways of forming a comparison; the one by placing the total annual expenditure in a rate on linear dimensions. The other, by bringing the same outlay to bear on the average discharge per second in cubic feet.

With the above in view, I shall take the average cost on the last six years incurred in maintaining the Eastern Jumna Canal, as during this period there has been a good deal of repair to the dams and channels in the

immediate neighbourhood of the head, and the cost offers perhaps a fairer comparison than were I to select periods of the same length, where the head works had had little spent upon them.

It appears from the year 1847–48 to the year 1852–53 the annual mean cost of current expenses on the Eastern Jumna Canal has been as follows :—

	RS.	A.	P.
Establishment, including European supervision and all items	37,585	12	11
Ordinary repairs	35,416	8	7
Total annual cost	72,002	5	6

The length of this Canal from the Jumna to Delhi is 137 miles 2 furlongs 186 feet, or say 137 miles. Its mean discharge per second may be estimated during the period above referred to at 800 cubic feet.

Now, in linear dimensions, the rate of cost per mile on the above data is as follows :—

	RS.	
Regular Establishment	274·35	per mile.
Ordinary repairs	258·51	,,
Total per mile	532·86	

Assuming the discharge per second as the basis of rate of expenditure, we have—

	RS.	
Regular Establishment	46·98	per cubic foot.
Ordinary repairs	44·27	,,
Total cost per cubic foot	91·25	

The length of the Ganges Canal main channels is 820 miles, with a discharge per second of 6,750 cubic feet. Taking the above rates on the Eastern Jumna Canal as our guide for obtaining the probable cost of the Ganges Canal current expenses, we have, in the first case, where linear dimensions are used—

	RS.
Regular Establishment	224,967·0
Ordinary repairs	211,978·2
Total current expenses per year	436,945·2

In the second, where discharge per second is considered:

	RS
Regular Establishment	217,115·0
Ordinary repairs	298,822·5
Total current expenses per year	515,937·5

As the action upon the channel is dependent entirely on the mass of water with which the works are connected, and as the amount of repairs depends upon this action, we may assume the total as shown by the latter table as the most likely to be correct. At any rate, that the amount therein stated is likely to be a probable charge for the annual current expenses of the canal. I would, however, take the mean between the two, and as an amount by which in its commencement the repairs and establishment of the canal might be limited, I would fix the sum of 475,000 rupees, of which the details for regular establishment and ordinary repairs would, on the proportion shown in the table founded on discharges, give to—

	RS.
Regular Establishment	200,000
Ordinary repairs	275,000
Total annual cost	475,000

In the early years of progress, we may, say for the first five years after water has been admitted, there will probably be many contingent expenses which may call for extraordinary outlay. The large quantities of river stone that will be required for the aqueduct flooring, and for the repairs of tails of masonry works in the Khadir; probable strengthening to the protective works on the upper levels of the Ranipoor and Puttri super-passages; excess of dimensions to the embankments of the aqueduct on that portion of the line where it passes through the deepest part of the valley, together with additional protective works which may be desirable on the Solani and Rutmoo rivers, both on their up- and down-stream faces, appear to me to render a further available sum expressly for Khadir purposes very desirable. I would rather

anticipate the probabilities of additional cost, and in so doing, point out the places where such may be called for, than leave the chance of such contingencies unmentioned or unprovided for. I should say, therefore, that for the first five years after water was admitted an annual sum of 125,000 rupees in addition to the amount of current expenses estimated for above, should be placed at the disposal of the Director of the Works for contingent purposes.

I have thought it necessary to devote a section of this chapter to the above, although I feel that in so doing, I am dealing with a subject which must to those acquainted with it appear to be of a very speculative character. The Report, however, would have been imperfect without attention being directed to cost of maintenance; and as the data upon which my figures have been derived are given, their value will be understood by my successor, whose experience on the works of the Eastern Jumna and his intimate knowledge of the difficulties attendant upon those of the Ganges Canal, will enable him to act accordingly.

I cannot conclude this Report without offering my best thanks to those who, whether above or below me, have so consistently aided the progress of the Ganges Canal works, from their commencement up to the present time.

From those above me, I have met with an indulgence and consideration, for which I can never be too grateful;—from those below me, a readiness of assistance and sympathy under all difficulties, that have from first to last been most encouraging.

Through so many years of progress, and with such a variety of works carried on under circumstances more or less understood, the executive engineers and officers in the different localities have largely aided me with their advice, suggestions, and recommendations. For these I am greatly indebted. I have endeavoured in the above Report to place to the credit of every one the merit

which appears to be his due. Should I have failed in doing this in any individual instance, I trust that the omission will be pardoned.

To Captain Baird Smith,* who succeeds me in the directorship of the Ganges Canal works, and to my excellent friend Mr. Harry Marten,† who, from the period of the early surveys of the canal, up to the present time, has been constantly with me, I have to offer my best thanks. From the first I have to acknowledge the aid afforded to me in looking over and correcting, and from the second in undertaking and completing the arrangement of the plans and manuscripts preparatory to their despatch to England.

To Colonel W. E. Baker, of the Bengal Engineers, whose name appears so often throughout this report, whose aid I can never be too thankful for, and whose friendship has been one of the bright lights in my Indian career, the last words of this report are dedicated.

Roorkee, April 8, 1854.

P.S. These pages cannot be closed without a passing lament over the memory of those who have been lost to us by the events of 1857–58—*Captain* Edward Fraser and Captain Francis Whiting; the first shot by his own men at Meerut, the last most cruelly murdered in the boats at Cawnpoor; Lieutenants Frederick Angelo, Brownlow, Span, all in the prime of life knocked down by this horrible Mutiny.

London, Sept. 1, 1860.

* Colonel Baird Smith, C.B., of the Bengal Engineers, Aide-de-Camp to the Queen, Mint Master, Calcutta

† Mr. Harry Marten, Inspector General of Accounts, Punjab and North-Western Provinces.

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